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Keith W. Carr
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List of Abbreviations and Symbols

ac	acre
°C	degrees centigrade
cm	centimeter
Cs	cesium
g	gram
HDPE	High Density Polyethylene
ICP-MS	Inductively Coupled Plasma Spectroscopy - Mass Spectrometry
IDNR	Illinois Department of Natural Resources
IDOT	Illinois Department of Transportation
IEPA	Illinois Environmental Protection Agency
INHS	Illinois Natural History Survey
ISGS	Illinois State Geological Survey
ISTC	Illinois Sustainable Technology Center
ISWS	Illinois State Water Survey
Kg	kilogram
lb	pound
LiDAR	Light Detection and Ranging (topographic survey method)
m	meter
mBq/g	millibecquerel per gram (measure of radioactivity)
mL	milliliter
mm	millimeter
n	number of samples
NIST	National Institute of Standards and Technology
Pb	lead
QA/QC	quality assurance/quality control
SOP	standard operating procedure
TNC	The Nature Conservancy
TWI	The Wetlands Initiative
µ	micro
USACE	United States Army Corp of Engineers
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UTM	Universal Transverse Mercator projection
yr	year
^{137}Cs	Cesium-137 (isotope used in radiometric dating of sediments)
^{210}Pb	Lead-210 (isotope used in radiometric dating of sediments)

Abstract

Restoring floodplains and backwater lakes along large rivers by removing levees requires understanding of the tradeoffs between heavy sediment loads along the main stem of the river versus the negative effects of sediment deposition on backwater lakes and wetlands. An opportunity existed to explore this question at a 1600-acre wetland bank site at the confluence of the Illinois and LaMoine Rivers within the LaGrange pool of the Illinois River waterway.

Mapping from 1904 shows a large backwater lake (Big Lake) in the same location where one exists at present. By vibracoring of backwater lake sediments and direct measurement of recent sedimentation rates, this project established a depositional history for this site from roughly 1914 to 2017. Radiometric dating (^{137}Cs), coupled with core morphology description, grain size analysis, and analysis of heavy metals in the cores, allowed calculation of a mean sedimentation rate into backwater lakes on the site (Big Lake and Crane Lake) of roughly 0.61 cm/yr from about 1914 to 2004. Direct measurement of sediment deposition in dry land areas of the site yielded estimates of 0.54 cm/yr (2002-2009) and 0.61 cm/yr (2011-2017). When combined with data from a 2006 lakebed survey, these rates would predict infilling of Big Lake completely in about 136 years. However, the re-working of sediments on-site by wave action appears to push sediments away from the lake basin and deposit them in higher elevation and more densely vegetated areas. This wave action results in perpetuating the shallow lake for over a century despite significant inputs of riverine sedimentation.

Executive Summary

Restoring floodplains and backwater lakes is a proposition often hindered by numerous unknown factors, especially in highly altered basins such as the Illinois River. In order to make the best management decisions for the main stem of the river, backwater lakes, and wetlands, it is essential to understand sedimentation patterns in formerly leveed sites that are newly opened to the river. An opportunity existed for such a study at an approximately 1600-acre site located at the confluence of the Illinois and LaMoine Rivers within the LaGrange pool of the Illinois River waterway. The site includes a 195-acre backwater lake (Big Lake) and several smaller lakes and sloughs. The Illinois Department of Transportation (IDOT) purchased the site for development of a wetland bank. Wetland hydrology restoration strategies included the cessation of seasonal pumping, ditch filling, drain tile removal, and either levee removal or natural levee degradation. The parcel is strategically located in a reach of the Illinois River area noted both for excessive sediment load and for high flood stages due to a floodplain constricted by levees.

Through a coring and sediment deposition study, the project established a sedimentation history for this site, from the period just prior to extensive agricultural development in the area, through the time of rapid anthropogenic change within the Illinois River basin, to the current and ongoing site sedimentation regime coincident with wetland restoration efforts. Radiometric dating of sediments, coupled with morphological examination of the cores, soil chemistry sampling, and grain size analyses aided in constructing the past chronology. The study also initiated a program whereby current and ongoing sedimentation rates on the parcel are measured site-wide. The aim was to outline the role that this site had in removing sediment from the Illinois River, as well as to determine ongoing sedimentation rates with the site un-leveed. The project also predicted the implications for the lifespan of the largest backwater lake on the site (Big Lake).

Historical sedimentation rates were determined by measuring Cesium-137 (^{137}Cs) activity in sub-samples of vibracores taken on site. Using the accepted peak year of fallout from atmospheric testing of nuclear weapons (1963), the radiometric data showed agreement from three separate lake cores establishing an average sedimentation rate of roughly 0.61 cm/yr for the period from 1963 to 2004. This rate was extended backwards and compared to grain-size data from the cores. A change in sediment character to a finer-grained (clay-dominated) depositional regime seems to occur between 1897 and 1914 (^{137}Cs dates). This data corresponds with a known historical event. That period was when a drainage district was organized and levees were being built on the site. Presumably when completed, the levees reduced the regular delivery of coarser-grained, silt-dominated sediments from the river to the lake basin. Both examination of morphological changes in the lake cores and lead (Pb) data from ICP-MS analysis of core samples lend support to this chronology, at least back to approximately 1914.

From 2002 to 2017, sedimentation rates were directly measured on site. Between 2002 and 2009, buried ISGS benchmarks were used, and from 2011-2017, a network of concreted steel stakes were used. These measurements represent sedimentation rates after the levees were breached in a large flood in 2002. Data from this period reveals that a single large flood can deposit a mean depth of sediment site-wide of over 2.3 cm with depths of as much as 5-6 cm in some locations. Over longer periods, average annual rates of 0.54 cm/yr (2002-2009) and 0.61 cm/yr (2011-2017) were measured.

Based on a survey of the bed in Big Lake during a complete dry-down period, a volume was calculated for the lake basin. Applying the filling rates based on measured historical and current sedimentation

rates, the lake would fill in completely in about 136 years. However, monitoring of sediment stakes in 2013, 2015, and 2017 indicates that wave action in the shallow lake likely re-suspends recently deposited lakebed sediments and moves them to peripheral areas of the site, which is the likely mechanism for perpetuating the lake since (at least) 1904 despite significant sedimentation rates. Data from this study generated an estimate for on-site sedimentation of a depth of ~35 cm (13.8 in) site-wide from 1963 to 2017, with obvious positive implications for reducing suspended sediment loads and channel siltation in the Illinois River.

Introduction

The re-connection of highly altered rivers to their former floodplains is a challenging proposition. The floodplains and associated wetlands typically are altered themselves and were generally formed under different hydrologic regimes. One particular challenge is balancing floodplain habitat quality (e.g., backwater lakes, wetlands) with restoring floodplain functions to improve river quality (e.g., reducing flood heights, suspended sediment loads, and channel siltation). Such is the case with the Illinois River and its major tributaries. Reducing sediment loads in the main stem of the river aids in maintaining a navigation channel, improves water clarity, and enhances species diversity of aquatic and benthic organisms. Less infilling of sand and gravel river bed materials by fine materials can enhance spawning opportunities in some species. The trade-off is that floodwaters and riverine sediment are allowed onto the floodplain. Other negative effects include the silting in of backwater lakes and sloughs, introduction of exotic species, and decrease in wetland plant species diversity that often accompanies sediment deposition. In addition, wetlands and shallow water bodies on the floodplain experience reduced light penetration and suppression of submerged aquatic vegetation growth as a result.

Some wetland restoration strategies advocate for (and practice) continued isolation of the floodplain from the river by the maintenance of levees. Alternatively, various other strategies that allow rivers to re-occupy floodplains have been undertaken in Illinois by agencies such as the Illinois Department of Transportation (IDOT), The Nature Conservancy (TNC), and The Wetlands Initiative (TWI). These range from partial connection via expensive, engineered control structures, or reduced-height levees to the restoration of an unencumbered connection by outright levee removal or by allowing natural levee degradation. River and wetland restoration managers throughout the Illinois River basin and the state need data to determine if these reconnected sites can act as sediment repositories for the river while still supporting ecologically beneficial and diverse backwater wetland areas. Data and analysis to evaluate rates of past and ongoing Illinois River floodplain sedimentation rates are needed to critically evaluate restoration approaches for this and other restoration strategies.

<u>Historical Context for the Illinois River</u>

Prior to inhabitation by Europeans, the Illinois River was a "free-flowing stream bisecting a broad floodplain" (Marlin, 2001), and the floodplain was scattered with "river marshes, long narrow sloughs, oval ponds or small lakes, and lakes of large size that were often amoeboid in shape" (Bellrose et al., 1983). Deposition resulting from overbank flows formed natural levees that were about 4 to 10 feet above the adjacent bottoms (Thompson, 2002). Some descriptions of the bottomland environment survive in the form of old maps, photographs, and field notes. An example of the latter, by Kofoid (1903), describes the bottomland lakes as "having clearer water, stained more from organic matter than by silt". This author also describes lakebeds of "soft black ooze", suggesting decay of organic matter likely outweighed clastic sedimentation. Abundant beds of submerged-aquatic vegetation, such as coontail, waterlily, smartweed, and river bulrush are also described, suggesting backwater lakes were clear enough for light to penetrate to the beds (Bellrose et al., 1983). Widespread watershed alterations began in the Illinois River valley in the late-1800s. Forests were cleared for timber and fuel and lands placed in agriculture, increasing in-basin erosion and sediment delivery to the river. The first navigation dams appeared in 1869, raising average water levels and reducing the overall flow velocity of the river. This change likely compounded the already increasing trend in sediment deposition resulting from rapid land clearing. Diversion of water from Lake Michigan into the Illinois River began in 1900 and peaked in about 1920 (Starrett, 1972). This increase, combined with the effect of the navigation dams, approximately doubled the surface area of backwaters in the Illinois River valley and deepened the backwater lakes and ponds (Bellrose et al., 1983). For example, in 1920, mid-summer low-water levels at Havana increased by as much as 7 feet (Starrett, 1972). Most of the navigation dams were replaced or upgraded in the 1930s, further raising water levels. As a result of these changes, some backwater lakes and bottomland sloughs were permanently inundated, whereas in a natural state they may have drained entirely at least once a year. This inundation had the effect of disrupting the natural hydrological conditions that supported backwater floodplain habitats.

During the early 1900s, further alterations were also undertaken in the form of floodplain "reclamation" by the construction of levees. The most significant period of floodplain losses to levee district formation was from about 1909 to 1922 (Mulvihill and Cornish, 1929). Widespread draining of backwater lakes and sloughs followed as large tracts of floodplain were separated from the river by levees and subsequently ditched and pumped. The most serious consequence of this process was that the levees, often on both sides of the river, constricted floodwaters, which increased flood stage on the river. Early studies showed that this impinging on the floodplain "reduced the space available for flow and storage" to the point where Walraven (1950) concluded that "a 1943 flood at Beardstown had a stage that was 9.7 feet higher than a flood in 1903 with a nearly identical discharge". According to Bellrose et al. (1983), as development of the Illinois River valley progressed in the mid-late 1900s, agricultural practices resulted in an alarming increases in sedimentation rates from tributary valleys. A study by Demissie et al. (1992) estimated that in a given year, only 41% of the 13.8 million tons of sediment delivered by tributary streams passes out of the lower Illinois River, leaving approximately 8.2 million tons in the river valley annually.

Background of Site and Current On-Site Conditions

The study site is a 1,645-acre floodplain, located at the confluence of the LaMoine and Illinois Rivers and at approximately river-mile 82-83 within the LaGrange navigation pool of the Illinois River waterway in Brown County, Illinois (Figure 1). The parcel was formerly a backwater lake, marsh, and floodplain forest environment (Woerman, 1904). Levees were constructed between 1915 and 1918, separating the floodplain from the Illinois and LaMoine Rivers, and the site was incorporated as the Big Prairie Drainage and Levee District (Thompson, 2002). The site was then drained via pumping, ditches, and drain tiles, and mostly converted to farmland by the 1920s. The largest backwater lake on site (Big Lake) was visible on the 1904 Woerman map (Figure 2). Contours and soundings on the map suggest a similar extent to the modern lake and a depth range of 2-4 feet (very similar to recent depths). During the leveed-off period, Big Lake and the other lakes and ponds on the site would generally fill from a combination of bluff and on-site runoff and high groundwater levels or through-levee leakage during periods of river flooding.

The site was purchased by IDOT in 2001 to develop a wetland bank, which is currently in operation (Figure 3). The aim of the IDOT project was to remove land from agricultural use, restore a more natural hydrologic regime, and restore, enhance, and preserve wetlands on the former floodplain. In addition to providing habitat for aquatic and terrestrial wildlife, another restoration objective for the wetland bank site is to provide a floodwater and sediment storage function benefitting the Illinois and LaMoine River watersheds. The hydrologic restoration, which began in 2000, involved cessation of pumping, deactivation of the drainage ditch and agricultural tile network, and re-connection of the floodplain to the main stems of the two rivers. The re-connection was accomplished by not repairing levee breaches that occurred in a 2002 flood. ISGS scientists have been involved in a hydrological monitoring capacity at the site for an extended period. This monitoring yielded an opportunity to use the site as a field laboratory to initiate this ISTC-funded project to study riverine sedimentation.

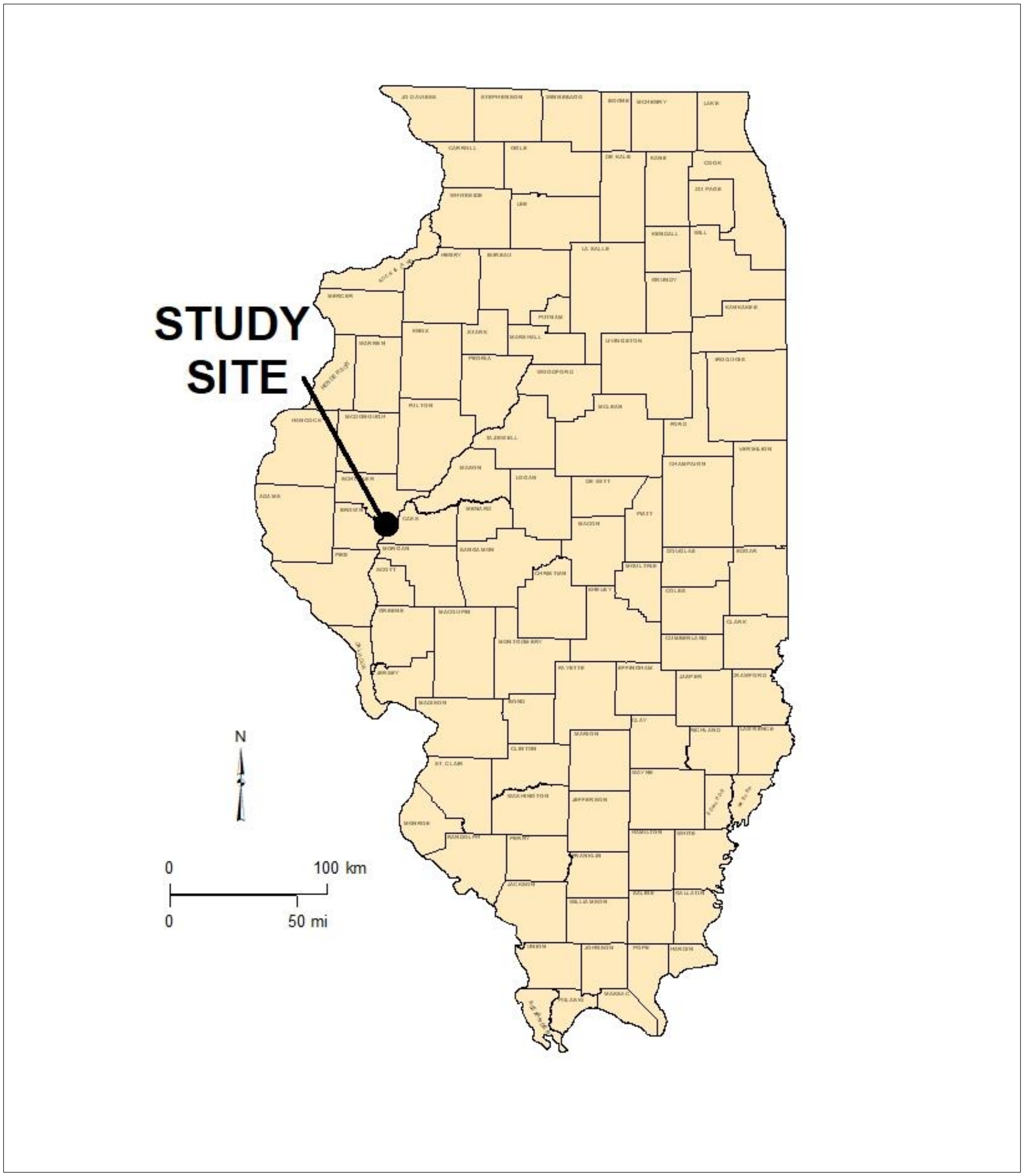


Figure 1: Study site location.

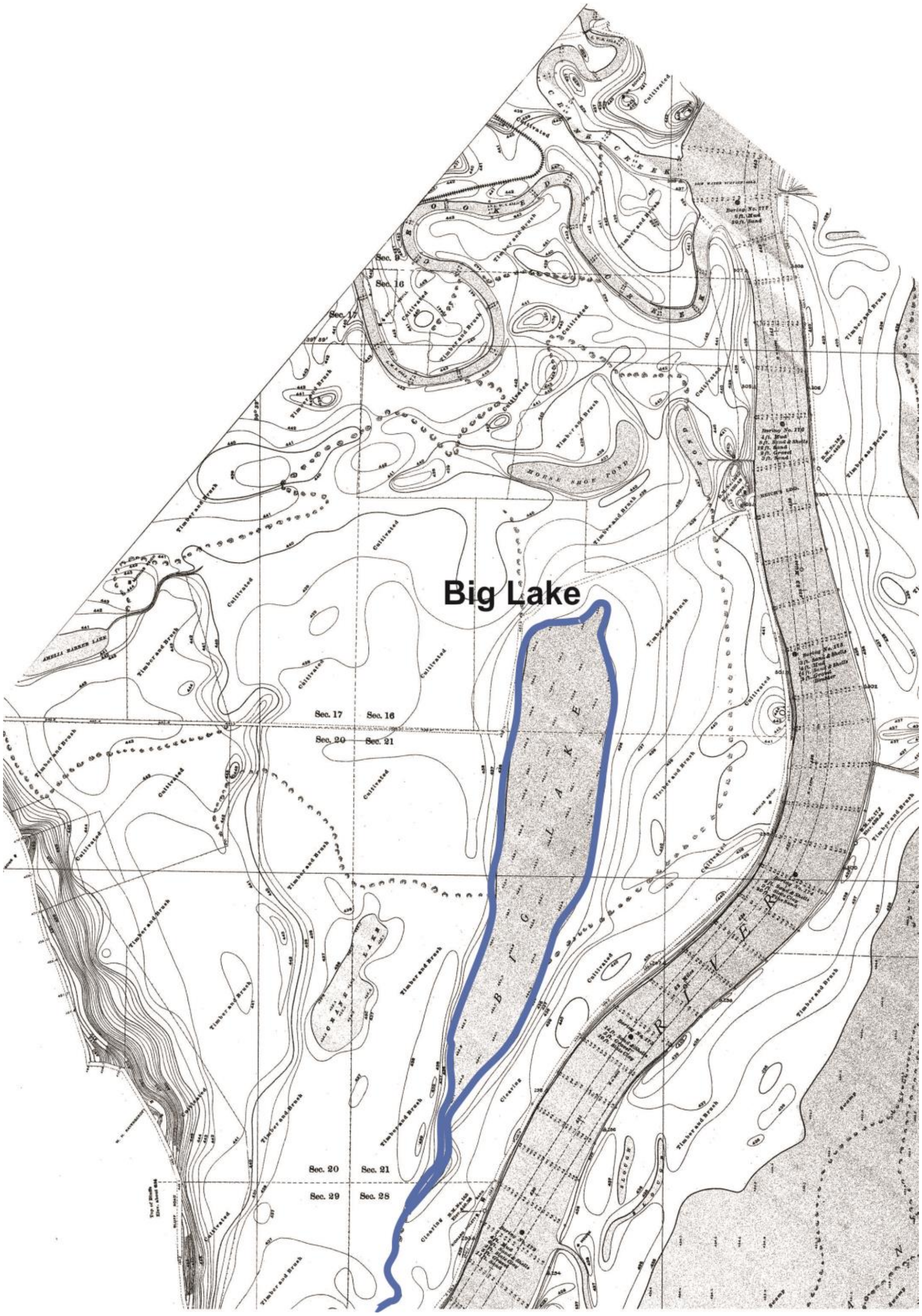


Figure 2: Big Lake as seen on Woerman map (1904).

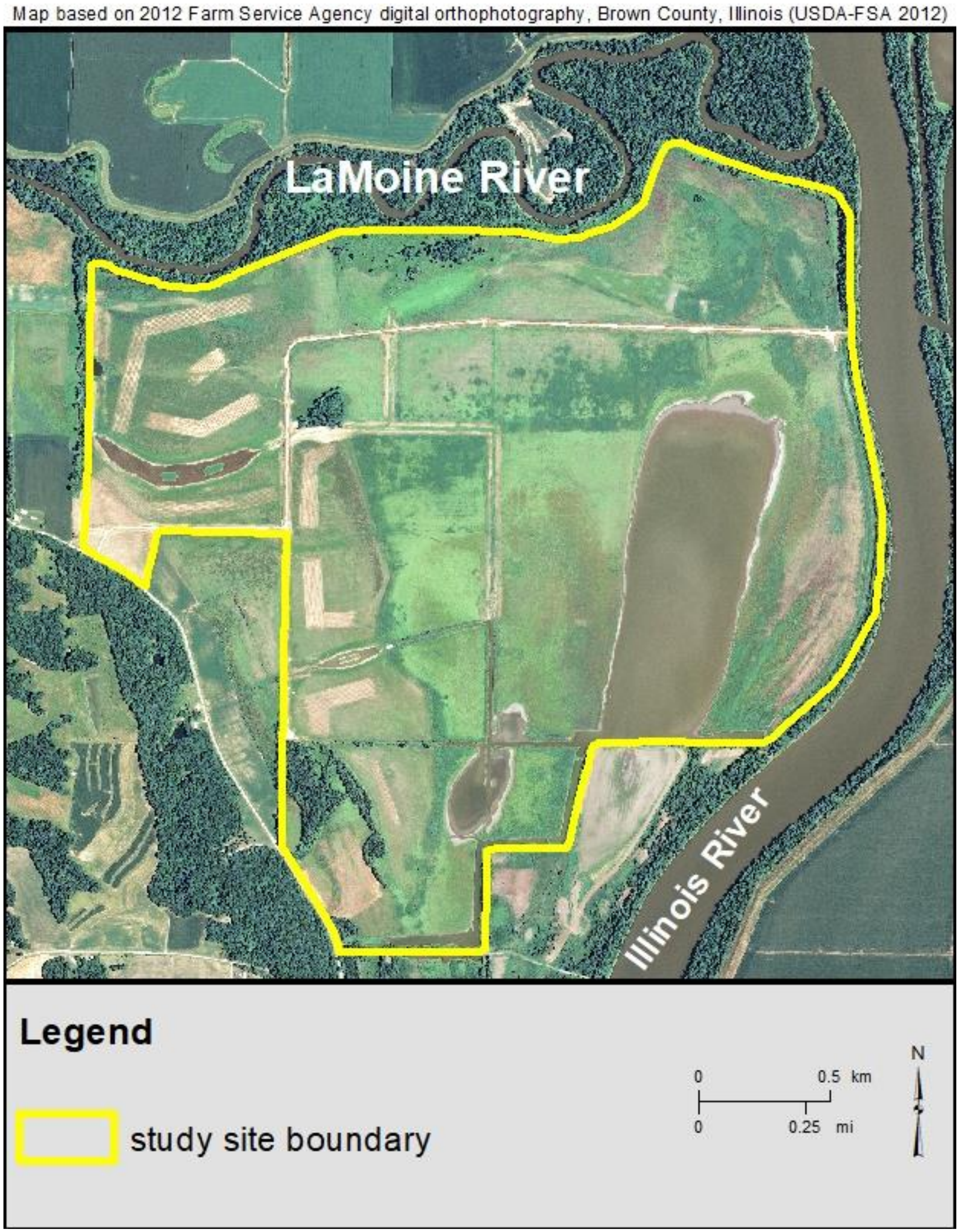


Figure 3: Study site base map. LaGrange Wetland Mitigation Bank Site.

At the beginning of the study, the land use at the site was primarily row-crop agriculture with a mixture of small areas of remnant wetlands, floodplain forest, and open water areas. The largest backwater lake (Big Lake) has a basin roughly 195 acres in size. Several smaller named lakes and unnamed sloughs are present, including Crane Lake (Figure 4). A local tenant farmer stated to ISGS that the lake was never pumped dry, but noted that the site was farmed right to the lakeshore some years. According to a 2002 levee system evaluation by the Illinois Department of Natural Resources (IDNR), the Big Prairie Drainage and Levee District was dissolved in 1964. The levee system was subsequently maintained by private farming interests (Tom Brooks, IDOT, pers. comm.). Also, the Big Prairie Drainage and Levee District was denoted as “abandoned” on Illinois River navigation charts in the 1974 edition (USACE, 1974).

In the 1970s, an additional levee was built, which now forms the southern property boundary. This levee truncated the southern third of Big Lake as it existed on the 1904 map (see Figure 3). In the 1980s and 1990s, the levees were occasionally repaired by topping up with a dragline crane. The 2002 IDNR evaluation also stated, “the levees are currently in poor condition, with a non-uniform cross-section and profile, and a heavy growth of trees". A LiDAR map of the site (Figure 5) details the major topographic zones on the site, with the darkest tones corresponding to the lowest elevations. These include lake and slough basins (which very seldom dry up), a lake plain area (which is inundated in most years), a fluvial terrace 5-8 feet higher than the lake plain (which floods in roughly one in two or one in three years), as well as alluvial fans adjacent to the valley bluff (to which floodwaters occasionally reach).

The site is currently connected to the Illinois and LaMoine Rivers at fairly low river levels through two breaches in the protective levee, which were created during a near-record flood in 2002 (for breach locations, see Figure 4). At a water level elevation (stage) of roughly 432 ft (a.s.I.), which is still 4.5 ft below flood stage, LaMoine River floodwaters can enter the site through the breach in the levee along the west site margin and Illinois River floodwaters can enter the site through the breach in the levee along the south site margin. A 36-inch culvert also provides some connection with the Illinois River. At an elevation of roughly 430 ft, it is only one foot above flat pool elevation of 429 ft, but well above typical summer low river levels of roughly 423.5 ft. In addition to riverine floodwaters, three small streams enter the site from the bluff, which comprise the southwest site margin, and deliver sediment from these upland areas. Although this contribution is likely minimal compared to riverine sediment sources.

Levee Constriction and Floodwater Relief

As early as the 1930s, USACE singled out the site (then called the Big Prairie Drainage and Levee District) as "alone amongst 34 tracts in offering the economic justification to warrant a return to floodwater storage and wildlife function" (Thompson, 2002). As early as the 1920s, the general site area has also been identified as an area where constriction of the floodplain is problematic. Even today, the levees at the site and levees on the east side of the Illinois River create a corridor that is only 1,300 feet wide. Another noteworthy "pinch," described by a local farmer, is a gap through which the LaMoine River flows at the northwest corner of the site (Figure 3). This constriction, which was widened via a levee setback in 1917, is still only 700 feet wide. This area, along with the north property margin (which is the LaMoine River levee), was described in a 2002 IDNR levee evaluation as an area where the "existing levee system encroaches upon the floodplain to an alarming degree" (T. C. Brooks, pers. comm.). As the site is located adjacent to these two noteworthy narrow levee gaps, relief in the form of floodwater storage is valuable for this area. However, regular influxes of riverine sediment are a consequence of this floodwater relief role for the site.

map based upon USGS digital orthophotograph, Cooperstown NE quarter quadrangle, produced from 4/14/98 aerial photography (ISGS 2002)

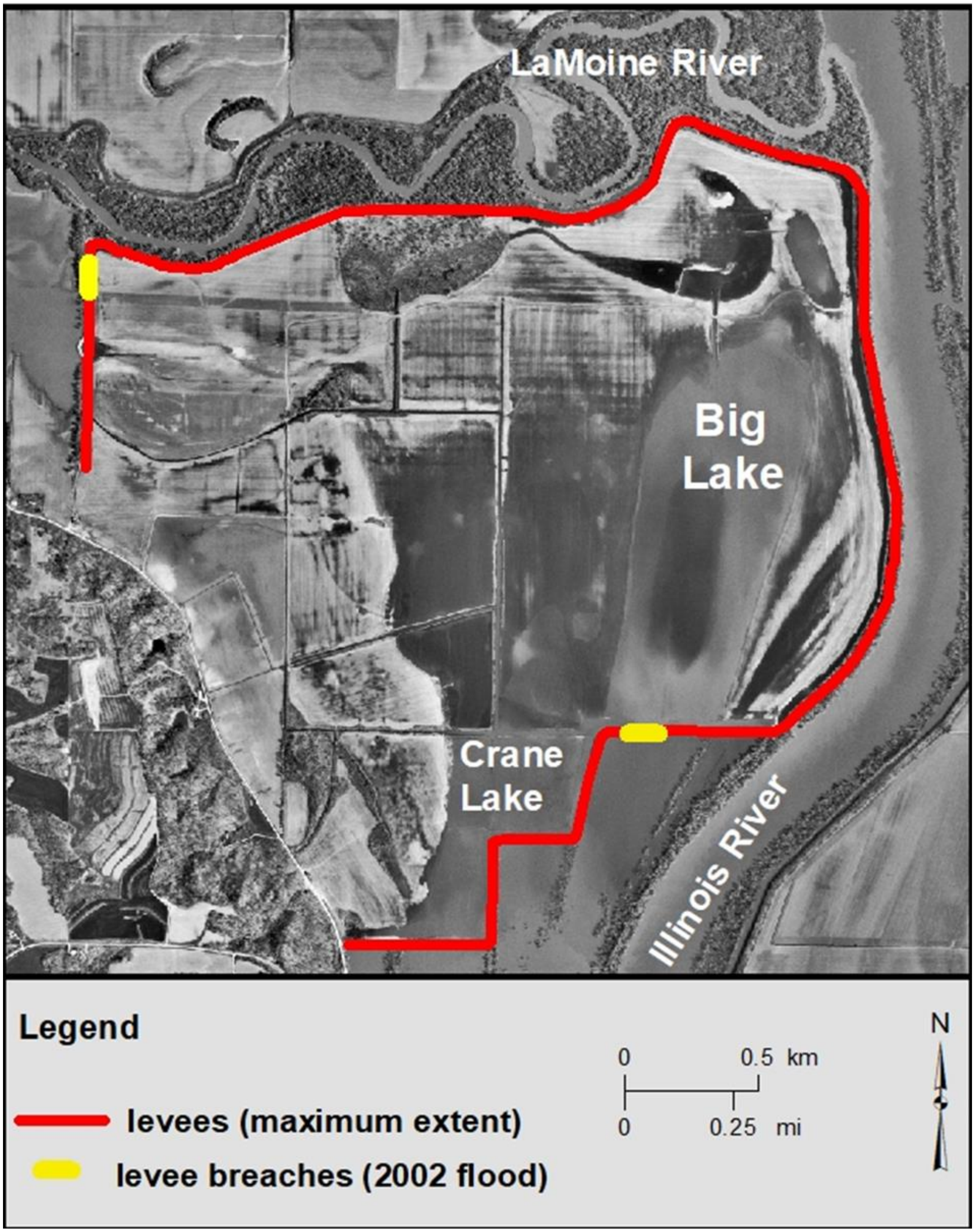


Figure 4: Site features and existing levees.

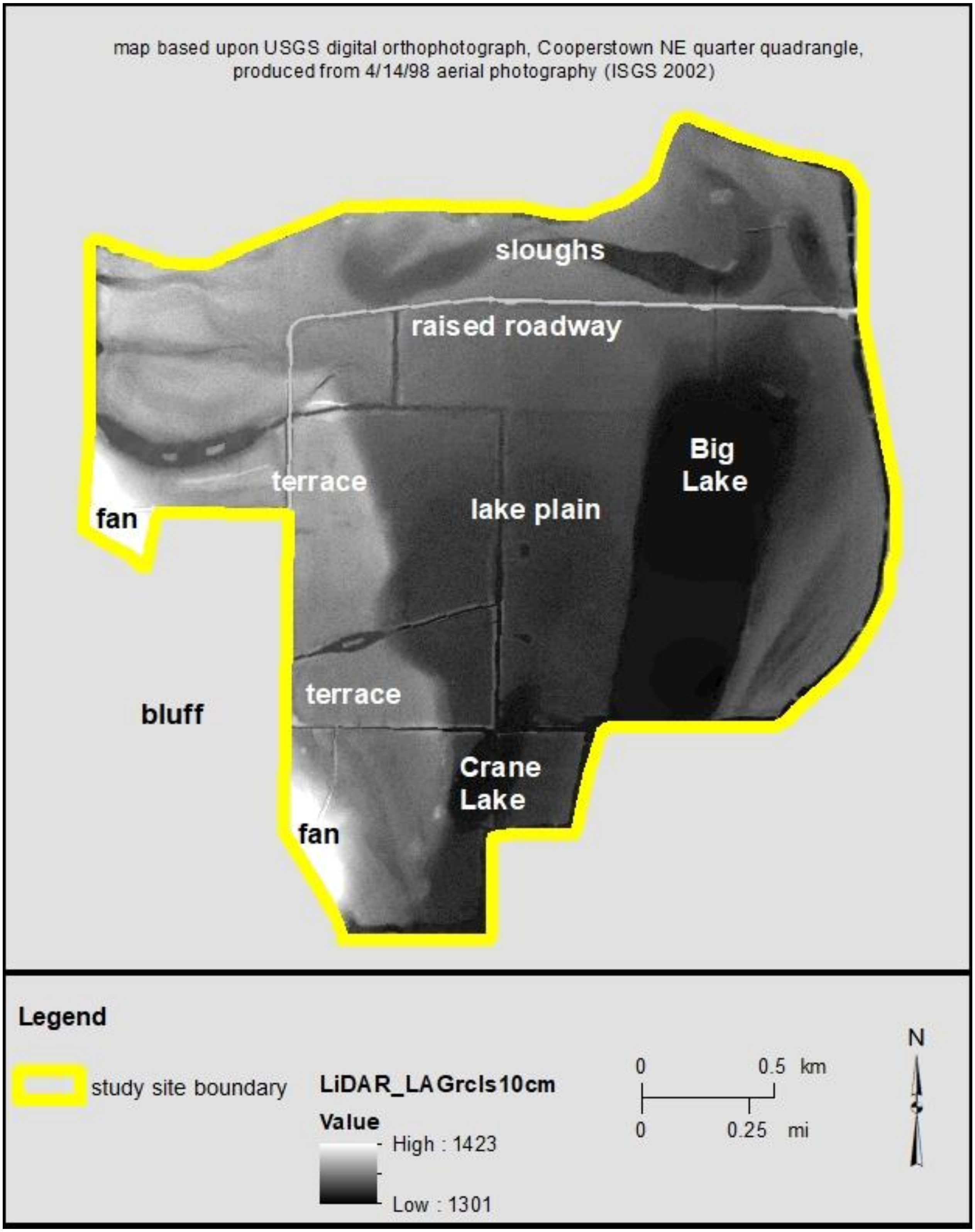


Figure 5: Site topography (LiDAR).

Local Sediment Loads

It is well established that the LaMoine River is a large contributor to the sediment problem in the lower Illinois River. According to a sediment budget by Demissie et al. (1992), the LaMoine River has one of highest suspended sediment loads of any major tributary entering the Illinois River. They further stated that "the most sediment flows into the La Grange pool with the Spoon, LaMoine, Sangamon, and Mackinaw Rivers being the main contributors." All four of these rivers are either adjacent to or upstream of the project site, clearly establishing the advantageous position of the site to either assist in removal of sediment from the main stem of the Illinois River or prevent a portion of it from entering it at all. United States Geological Survey (USGS) data obtained by ISGS shows that over a ten-year period (1984 to 1997), the LaMoine River had 60% higher turbidity readings than the Illinois River. In one year, where continuous monitoring data were available (1980-81), the average daily suspended sediment concentration (in mg/m^3) in the LaMoine River was double that of the Illinois River. On an aerial photograph of the site from April 1998, a clearly defined sediment plume can be seen exiting the LaMoine River into the somewhat less turbid waters of the Illinois River and back-flowing into the site from the south (Figure 4).. As LaMoine waters can also directly enter the site at the northwest levee breach, the site is uniquely positioned to act as a sediment repository.

Negative Ecological Effects of Excessive Sedimentation

Post-glacial sediment on this site has likely been deposited under three general regimes:

- Pre-settlement period of essentially "pristine" conditions
- Period dominated by increasing human alteration in the basin, isolation of the site from the river and intensive agriculture
- Regular connection of the floodplain to the river (current regime)

Of concern is the potential for significant sedimentation on-site in the current un-leveed configuration with its use as floodwater relief and the juxtaposition of a very high sediment producing tributary.

Excessive sedimentation and turbidity has well-known negative effects on habitat (Belrose et al., 1983). These include degradation of fish spawning beds and resulting species loss, reduction of light penetration to aquatic plants, and reduction in dissolved oxygen, bottom fauna, and planktonic food supply for panfish. Erosion and sedimentation in the river channel and un-leveed backwater areas is widely recognized as the principle cause for most of the environmental and ecological problems in the Illinois River Valley (Demissie et al., 1992). These authors also stated that "even though it is repeatedly acknowledged that erosion and sedimentation are the main problems in the Illinois River, detailed studies on the issue are rare." Benefits of reduced sediment deposition in river channels, and the reduction of suspended sediment for riverine aquatic species are well known and well studied. Once these riverine loads are routed onto floodplains through levee removal projects, the rates of suspended sediment deposition and impacts to backwater lakes and wetlands are less well known.

Fate of Backwater Lakes

According to Bellrose et al. (1983), prior to the diversion of Lake Michigan waters in 1900, some backwater lakes had depths as great as 12-16 feet, although most were 4-6 feet deep. To attempt to quantify the change since the turn of the century, these authors surveyed the volume of 21 bottomland lakes in the late 1970s. They determined that by 1976-79, the average depth of these lakes was only about two feet. Lakes in the La Grange pool were especially shallow, averaging only 1.8

feet (Bellrose et al., 1983). Although backwater sedimentation is empirically obvious along much of the lower Illinois River, there is little data on modern backwater sediment deposition rates in this portion of the Illinois River watershed, and there is no modern bathymetric survey of Big Lake in particular. In a sediment budget study by Demissie et al. (1992), the authors stated that their estimates of lake capacities and sedimentation rates were still based upon data collected in 1975, the most recent available. They further recommended that it was "essential that a complete and reliable sedimentation study of the backwater lakes in the Illinois River valley is conducted". Also, according to Demissie and Bhowmik (1986), "most of these lakes are connected to the main river by narrow outlet channels". The subject site, with the exception of a few levee breaches, which were quickly repaired, has more or less been isolated from riverine sediment since about 1915-1918. This isolation provides an interesting contrast to sedimentation in backwater lakes that have been continuously connected to the river. In addition, the site offers a chance to study recent sedimentation rates, which rare for lakes anywhere in the La Grange pool of the Illinois River. A recent study by Cahill et al. (2008) only cored and sampled lakes that are continuously connected to the river, and to their knowledge, prior to this study, Big Lake itself had never been cored.

Purpose and Objectives

The purpose of this study was to investigate the sediment trapping role and sediment storage potential of this large floodplain site and to predict the lifespan of Big Lake based on measured sedimentation rates. This report includes data aimed at two data collection periods of the site's history:

1. Coring study to determine historical backwater lake sedimentation rates
2. Setup and monitoring of a sediment monitoring network outside the confines of the lakes and site-wide to determine current and ongoing sedimentation rates

This report details the findings of the historical study and summarizes data from the recent and ongoing study up to 2017.

The study had two objectives. The first objective was to determine the past sedimentation rates for the backwater lakes and environs. To meet this objective, cores were taken in Big Lake, Crane Lake and a lake-margin area. A chronology was established via radiometric dating, supported by morphological examination of the cores, grain size analyses, and chemical analysis of sediment quality. The second objective was to estimate the current and ongoing sedimentation rates adjacent to the backwater lakes and site-wide. This involved the initiation of a program to routinely measure ongoing sedimentation rates in dry-land areas normally inundated only during floods. As part of this objective, a survey of the lakebed was undertaken with the aim of estimating its lifespan given current sedimentation rates.

Methods

Coring Procedures

Sediment cores were collected using a vibracoring system, developed by the Illinois State Water Survey (ISWS). The system consists of a Model P-3c vibracorer head, manufactured by Rossfelder Corporation, and mounted on an 18-foot pontoon boat (Figures 6 and 7). The field operations, including deployment of the rig and collection of seven cores, were all undertaken in one day (July 8, 2004). With the vibracoring method, the core collection tube is steadily driven into the sediments using high frequency vibrations. This method allows the collection of samples that are relatively undisturbed and with minimal compaction, recovery losses, and sidewall smearing inherent in other coring methods. According to an ISWS fact sheet, this apparatus has been successfully used in at least six studies of Illinois River backwater lakes, and sample recovery rates of 80-90% are typical in silt and clay lake deposits. Also, cores collected in this manner are typically well-suited for chemical and physical characterization, as well as for radiometric dating. Cores were taken at two locations within Big Lake, at one location within Crane Lake, and at one location in an off-lake area (Figure 8).

At each coring location, ISWS personnel collected GPS location with a hand-held GPS unit, and a stake was driven into the lakebed for later identification of the coring location by ISGS. Also, at each core location, water depth was measured and a Ponar sampler was used to collect a "grab" sample of the sediments at the surface of the lake bottom. Upon removal from the sampler, the sample was homogenized in a clean bowl, and a representative portion sealed in a 250 mL jar labeled with the date and ISWS core location number.

At coring location 1, in the southeast portion of Big Lake, two cores were collected (ISWS cores 149 and 150). Points of refusal were encountered at depths of 5.5 ft (1.68 m) and 4.8 ft (1.46 m), respectively. The water depth was 4.2 ft (1.28 m) at this coring location. At coring location 2, in the north-central portion of Big Lake, two cores were collected (ISWS cores 151 and 152). Points of refusal were encountered at depths of 4.3 ft (1.31 m) and 4.9 ft (1.49 m), respectively. The water depth was 4.3 ft (1.31 m) at this coring location. At coring location 3, in the center of Crane Lake, two cores were collected (ISWS cores 153 and 154). Points of refusal were encountered at depths of 3.5 ft (1.07 m) and 3.3 ft (1.01 m), respectively. The water depth was 3.5 ft (1.07 m) at this coring location. At coring location 4, a flooded off-lake area to the west of Big Lake, one core was collected (ISWS core 155). The point of refusal was encountered at a depth of 2.0 ft (0.61 m). Due to the limited recovery, a second core was not taken at this location. The water depth was 2.5 ft (0.76 m) at this coring location.

Figure 6: Illinois State Water Survey rig being anchored into position on the lake.

Figure 7: The Rossfelder P-3C vibracore unit driving the 4” coring tube into the lake sediments.

map based upon USGS digital orthophotograph, Cooperstown NE quarter quadrangle, produced from 4/14/98 aerial photography (ISGS 2002)

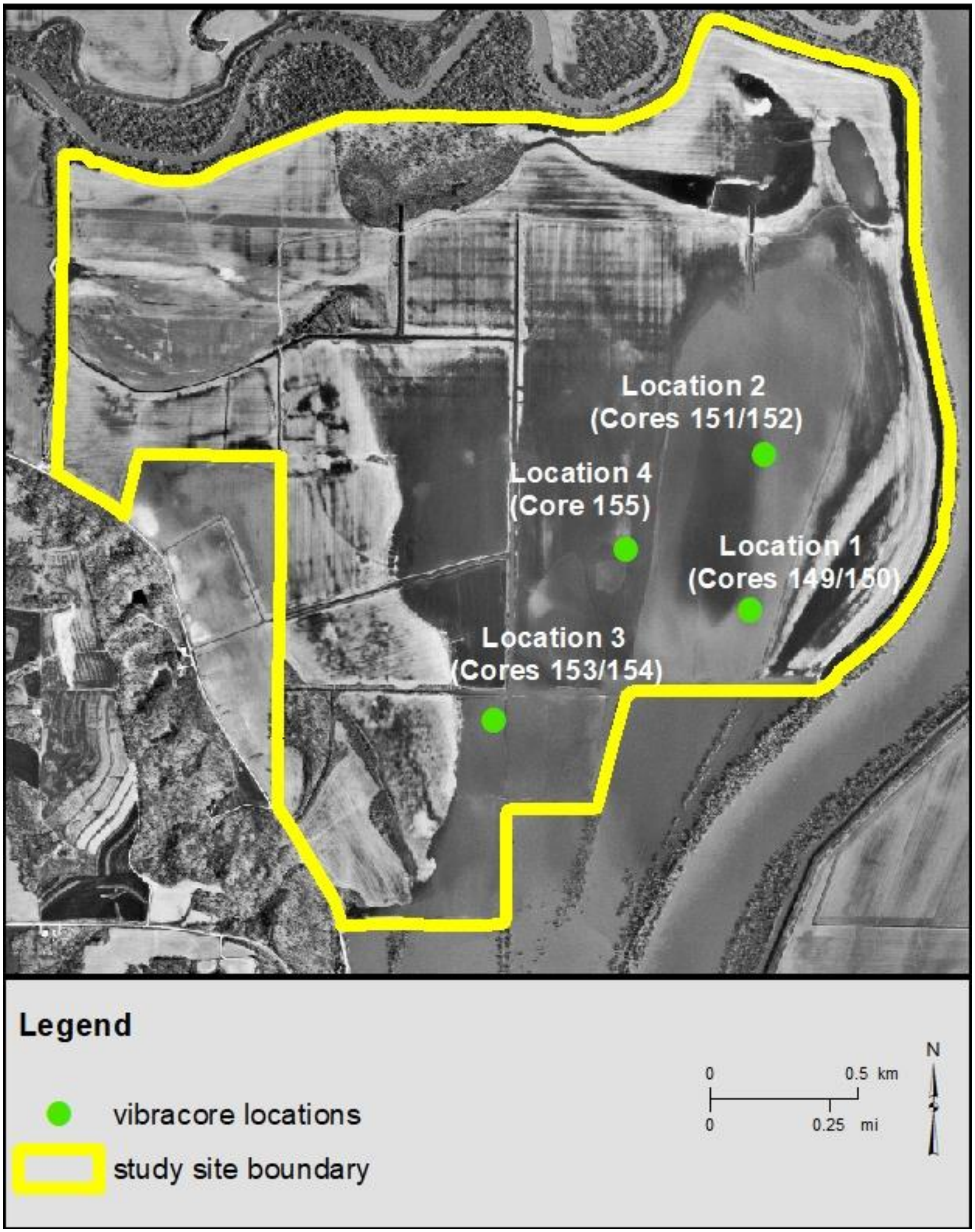


Figure 8: Vibracore locations in the backwater lakes.

At least one core (cores 150, 151, 153, and 155) at each of the coring locations was collected in specially prepared core tubes to maintain sample integrity for chemistry sampling. The core tubes, composed of HDPE (High Density Polyethylene), were washed with Ecolab Microtox detergent and rinsed with deionized water. This step was followed by a wash with 10% nitric acid and a second rinse with deionized water. The duplicate, complementary or geotechnical cores (149, 152, and 154) for potential use in other projects were collected in the same manner and were also stored in new (and similarly prepped) HDPE core tubes. After collection, the core tubes were capped, taped shut, and packed into rigid PVC tubes for transport. Appropriate sample chain of custody forms, signed by Jim Slowikowski (vibracore operator) and Keith Carr (project PI), accompanied the cores off the site.

The duplicate cores taken at each location have been properly stored and were left undisturbed for sharing with any interested PRI or outside scientists who may be interested in examining or analyzing the sediments for their project-specific goals.

Radiographs of the Cores

Once removed from the field and prior to core description, radiographs (X-rays) of the cores were taken at the University of Illinois' Veterinary Clinical Medicine Imaging Laboratory. A total of 13 images were created of cores 150, 151, 153, and 155 (at least one core from each of the on-site coring locations) using a General Electric Advantix 80-kW HF unit (Figure 9). Radiographs were made using Kodak Lenex fine screen 18 x 43 cm, double emulsion film. The settings used were 100 cm FFD, 80 kV, 0.25 sec at 400 mA. As they were done before the core was cut, these radiographs can document sedimentary structures in the cores that are often not observed by conventional means and that may be obscured when the core is halved. Often visible are fine laminations, plant matter, and shell layers that can be disturbed as the core is removed from the casing. The radiographs were backlit and examined (Figure 10), then put aside for use in the later construction of the detailed core logs.

Core Description

Prior to description or sampling, the core liners must be removed so the core is accessible. The casings were cut lengthwise, using a router, to a depth that would not penetrate the sediment. The shavings from the core liner were then removed with a commercial vacuum and the remaining liner thickness cut with a utility knife. The sediment core was then divided into two halves using a 0.2-cm diameter copolymer trimmer line. Once cut, the sediment cores were photographed, and the digital images were combined using Adobe Photoshop to produce a single color plate for each core (Figures 11-14). At this point, the cores were ready for description and sub-sampling. One core from each of the four sampling locations was processed in this manner (cores 150, 151, 153, and 155).

The description of the core included the texture and consistency, the Munsell color, the presence of any mottling, the presence of shells or plant debris, and the changes in sediment characteristics with depth. Each sampled and described interval was also tested with a 2% solution of a-a' dipyridyl for the presence of reduced iron. This test indicates if the interval has experienced primarily anaerobic or reducing conditions and is a quick indicator of hydric (or wetland) soil-forming conditions.

A model 29-3729 pocket penetrometer was also used to provide a classification of the unconfined compression strength of the material. An adapter foot was used for the softer, fluid material. Readings were made approximately every foot. Unconfined compression strength in sediment cores is measured in tons/ft^2.

Figure 9: X-rays of the cores being taken at the UI Veterinary Medicine facility.

Figure 10: Radiographs of the cores being examined for sedimentary structures.

Figure 11: Core from Location 1 (core 150) from the southeast portion of Big Lake.
(at top left is the current lake bed, bottom right is the base of the core at depth)

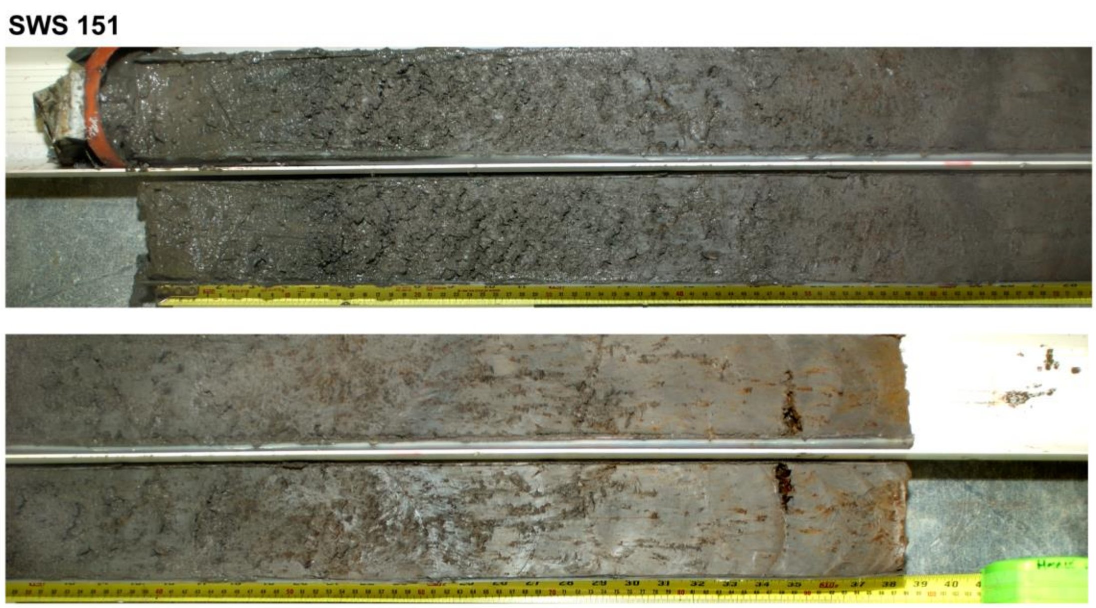


Figure 12: Core from Location 2 (core 151) from the north-central portion of Big Lake.
(at top left is the current lake bed, bottom right is the base of the core at depth)

SWS 153

Figure 13: Core from Location 3 (core 153) from the center of Crane Lake.
(at left is the current lake bed, at right is the base of the core at depth)

SWS 155

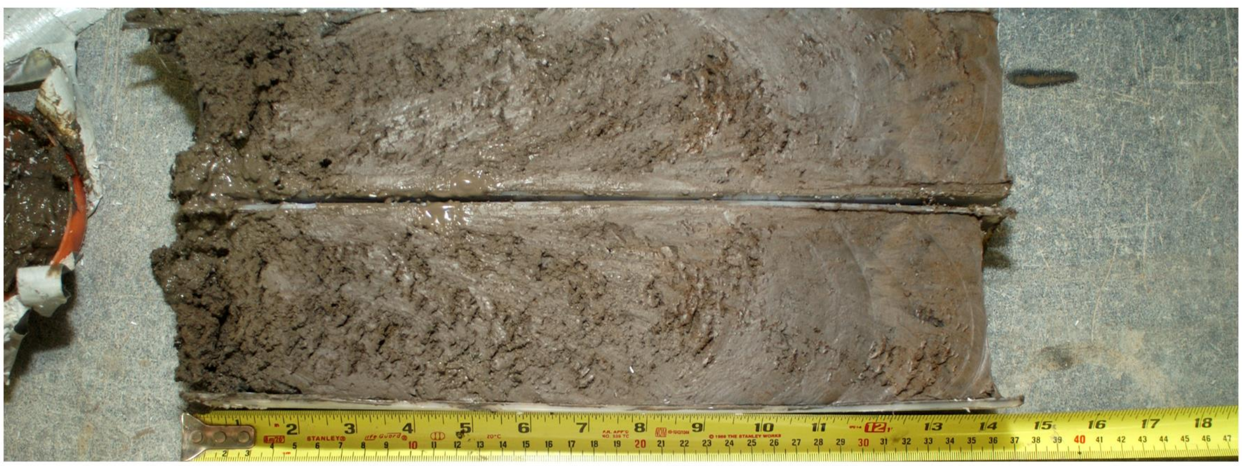


Figure 14: Core from Location 4 (core 155) from an off-lake area (lake plain) west of Big Lake.
(at left is the ground surface, at right is the base of the core at depth)

Sub-Sampling the Cores for Various Analyses

Sediment samples were collected from the cores according to standard ISGS procedures. The two (roughly 1.1m) cores from Big Lake (150, 151) were sub-divided into twelve intervals (Figure 15), while the shorter cores from Crane Lake (153) and from the off-lake area (155) were sub-divided into eight and seven intervals, respectively. Once removed, each segment was then weighed (Figure 16). A split was then taken (of roughly 50 grams wet weight) which was dried at 110°C to determine moisture loss. These data were used to calculate wet and dry bulk density, after which, the dried samples were discarded.

Organic Carbon Analysis

Organic carbon analyses on two of the lake cores (150 and 153) and the off-lake core (155) were also done using the ISGS lab. Sediment samples were analyzed for total and inorganic carbon by coulometric titration of carbon dioxide released from a sample by either combustion (for total carbon) or acid evolution (for inorganic carbon). Organic carbon was calculated as the difference between total carbon and inorganic carbon (Cahill et al., 2008). Organic carbon versus depth data can help determine if there were significant and prolonged still-stands of wetland conditions on-site.

Radiometric Dating Procedures

Determining the age profile of cores such as these typically employs radiometric dating, commonly utilizing Cesium-137 (^{137}Cs) as the indicator. ISGS has the expertise and equipment to perform ^{137}Cs dating in-house. This method is effective for dating sediments deposited since the early 1950s, and has been "successfully used by Cahill and Steele (1986) and Cahill and Autrey (1987) in Illinois to study sedimentation processes in lakes associated with the Illinois and Mississippi Rivers" (Demissie et al., 1996). One core from each coring location (150, 151, 153 and 155) was subjected to this analysis.

For dating via ^{137}Cs, a second split of ~400 grams was collected from each sub-sampled interval in all four cores, placed in petri dishes, and air dried in a laminar flow clean bench. These dried samples were then stored in pre-cleaned 250 mL QEC bottles. These ~400 g dried samples were ground to pass through a 1 mm mesh sieve. A split of 10 g was then taken for the analyses, and the ^{137}Cs activity of each 10 g split was determined by counting the gamma activity with a 42-percent efficient Ge(Li) detector for a minimum of 24 hrs. The 662 keV photon activity in sediment samples were compared to the activity of NIST Standard Reference Material 43508.

Plots of ^{137}Cs activity versus depth in the cores were then used to select the position in the sedimentation record when fallout from the testing of nuclear weapons in the atmosphere began to be deposited in significant quantities, also known as “onset” (1954) or the accepted “peak” time of fallout from nuclear weapons testing (1963). Sedimentation rates were calculated with both of these dates as a marker. The extent of the agreement between the two rates is useful in assessing the uniformity of the sedimentation rates in an area.

Grain Size Analysis

Samples from the cores were also submitted to a lab at the ISWS for grain size analyses. The sample intervals were the same as those for the ^{137}Cs samples and standard chain of custody forms accompanied the samples, generated and signed by the PI (Keith Carr) and the ISWS grain size lab supervisor (Laura Keefer). The ISWS lab procedure involved removing organics, doing a split between the sand-sized (and coarser) fraction and the fine materials, followed by a determination of the silt/clay fraction at intervals of 0.031, 0.016, 0.008, 0.004, and 0.002 (mm). As Big Lake was the focus of the coring study and had the longest core lengths recovered, only the two cores from within the lake were submitted for a grain size profile (cores 150 and 151).

Figure 15: Cores are subsampled for various analyses.

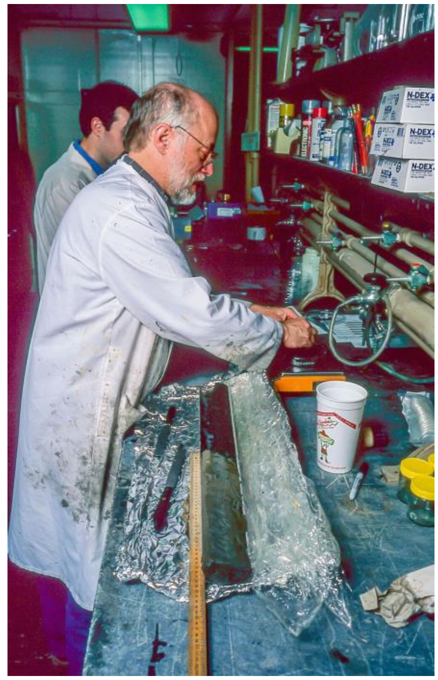


Figure 16: 50g splits are taken at each interval and the sub-samples weighed and dried.

ICP-MS Soil Chemistry Analysis

A set of samples were also prepared to have inorganics analyzed via ICP-MS. A total of 34 samples from cores 150, 153 and 155, as well as four grab or Ponar samples from the lakebed surface, were ground to 1.0 mm, at which point, a 30 g split was taken and ground to <60 mesh. For the purposes of this study, metals data from these sediment analyses can provide support for the ^{137}Cs chronology by determining at what depth certain anthropomorphic materials show up or are absent in the profile. For example, if a certain chemical constituent, such as tetraethyl lead from automotive fuels, was known to have not been in the environment prior to a certain year or general time period, this can lend support to a radiometric dating chronology.

The analyses were done at an outside contract lab, ActLabs in Ancaster, Ontario, which is accredited by the Canadian Association of Environmental Analytical Laboratories to meet the requirements of the International Standard Organization 17025. The sediment samples were digested in aqua regia at 90°C in a microprocessor controlled digestion box for 2 hours. The solution was diluted and analyzed by ICP-MS using a Perkin Elmer SCIEX ELAN 6100. The concentrations measured were not "total" concentrations of each analyte because unaltered silicates and resistant minerals may not have been dissolved.

Lake Basin Survey Procedures

An unusually long dry period from summer through fall 2005 caused Big Lake to dry up completely and allowed a direct survey of the lake basin in January 2006. A total of 12 west-east transects, roughly 500 ft apart, were laid out via GPS on site (Figure 17). Four benchmarks, concreted to a depth of 4 ft, were placed on the west ends of transects 4 and 5 and the east ends of transects 6 and 7 to act as nearby reference points to survey the basin. These stations were tied into the on-site topographic network from an existing ISGS benchmark at the southeast corner of the lake. A Leica TCR703 total station was used to measure lake basin topography and is capable of sub-centimeter accuracy at the ranges involved in this survey.

The ends of each transects were marked with flagged steel fence posts and a 12 inch nail for later relocation. The prism rods were outfitted with a broad, flat aluminum base 3 inches in diameter for obtaining a representative surface for each shot in the soft sediment of the lake basin. Shots were obtained at intervals along the line of approximately 100 ft, or occasionally less at the discretion of the survey assistant if rapid changes of elevation were apparent. In total, 326 shots were obtained in the basin, which is a reasonable point density for the broad, saucer-shaped bottom profile of the lake. As it was shot from the same datum as the site topography, the lake basin survey was easily incorporated into the site-wide digital topographic model (DTM).

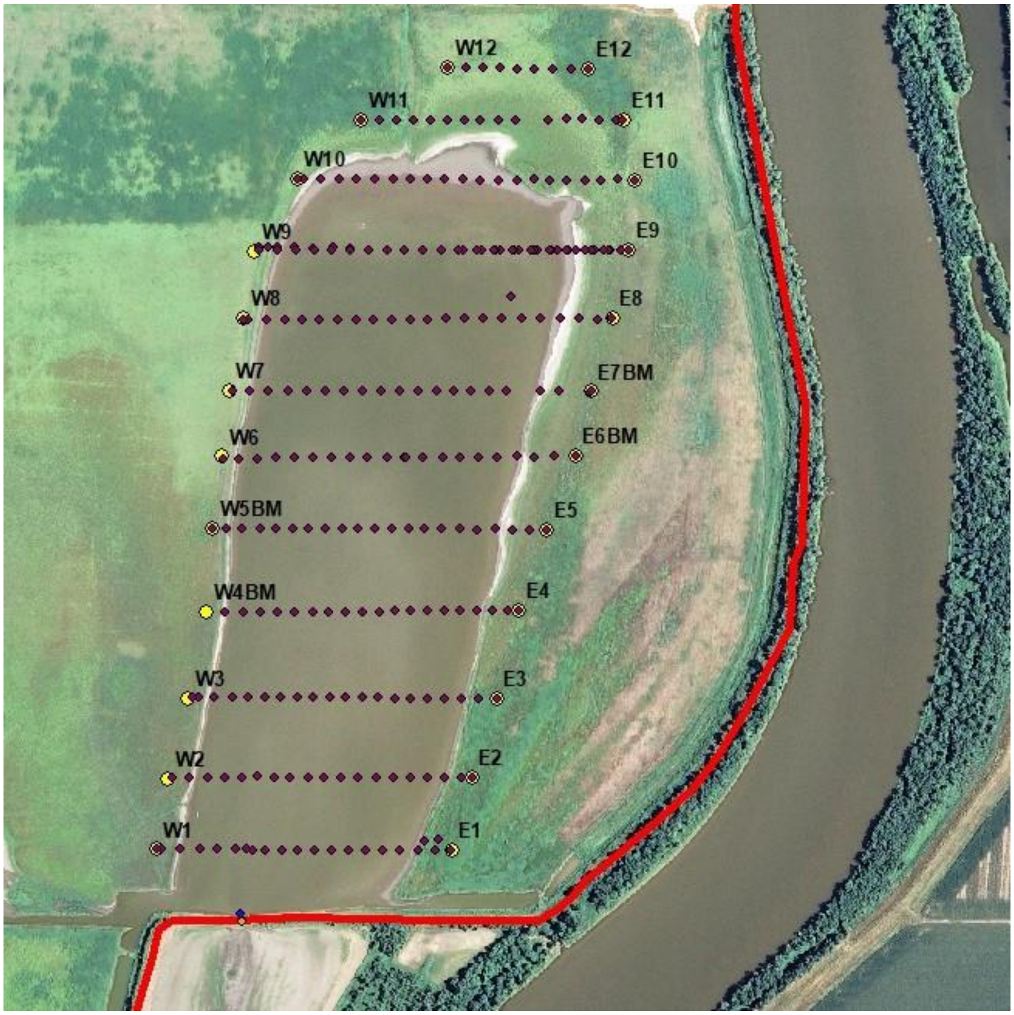
<u>Dry-Land Sedimentation Measurement and Rate Estimate</u>

An initial estimate of sedimentation rates could be gleaned from ISGS-emplaced survey benchmarks already on-site. This network consists of nine stations, with 8 ft steel rods emplaced flush with the ground surface and concreted in place (Figure 18). These stations, emplaced during the second week of May 2002, were located by magnetometer and sediment depths measured over them on July 27, 2009. The measurement method involved the 1" steel benchmark post being exposed, a straight edge placed across the hole, and the vertical depth to the benchmark measured (Figure 19).

In December 2011, over two field days, a total of 14 stakes were added site-wide and over a wide elevation gradient (Figure 20). As with the benchmarks, the stakes were emplaced in concrete below the frost line to minimize frost heave. The first three feet of the hole were 8" in diameter and the remaining two feet were 3" in diameter. The 1" steel posts (8 ft long) were installed to stand roughly one meter above ground surface (Figure 21). Concrete was mixed on-site and the hole filled to grade. The top surface was smoothed as sediment depth would be measured to this surface. The stakes were then painted, flagged and accompanied with a fencepost to protect from mowing. Once the concrete was set, the ISGS survey-grade GPS was used to measure the X/Y location of the stake, top-of-post elevation, and elevation of the concrete surface.

Visits to the site to measure sediment depth were originally planned to be undertaken annually, but in practice, on-site flooding conditions limited access at times. Upon arrival at each stake location, the vegetation was gently cleared from the top of the sediment covering the concrete pad around the stake (Figure 22). The distance from the surveyed elevation (top of the stake) to the sediment surface was measured, at which point a slice of sediment was removed from the pad and measured in-place (pad to top of sediment) or if it came easily as a "ped" or block, it was measured with calipers (Figure 23). At each stake, three measurements of either the ped or the pad to top of sediment were made and the mean sediment thickness recorded. These measurements were typically within three millimeters of one another, yielding a rough measurement error (+/- 3.0 mm). Care was taken to replace the soil in the slice, because the measurements were to be cumulative over time. Sediment depth data from the stakes from 2013, 2015, and 2017 were then contoured using ArcMap to produce isopach (thickness) maps of sediment depth on-site.

A. *Establishing elevation of concreted transect benchmark with survey-grade GPS.*



B. Lake transects and shot density for the lake bottom survey.

Figure 17: January 2006 survey of Big Lake bottom during complete dry down.

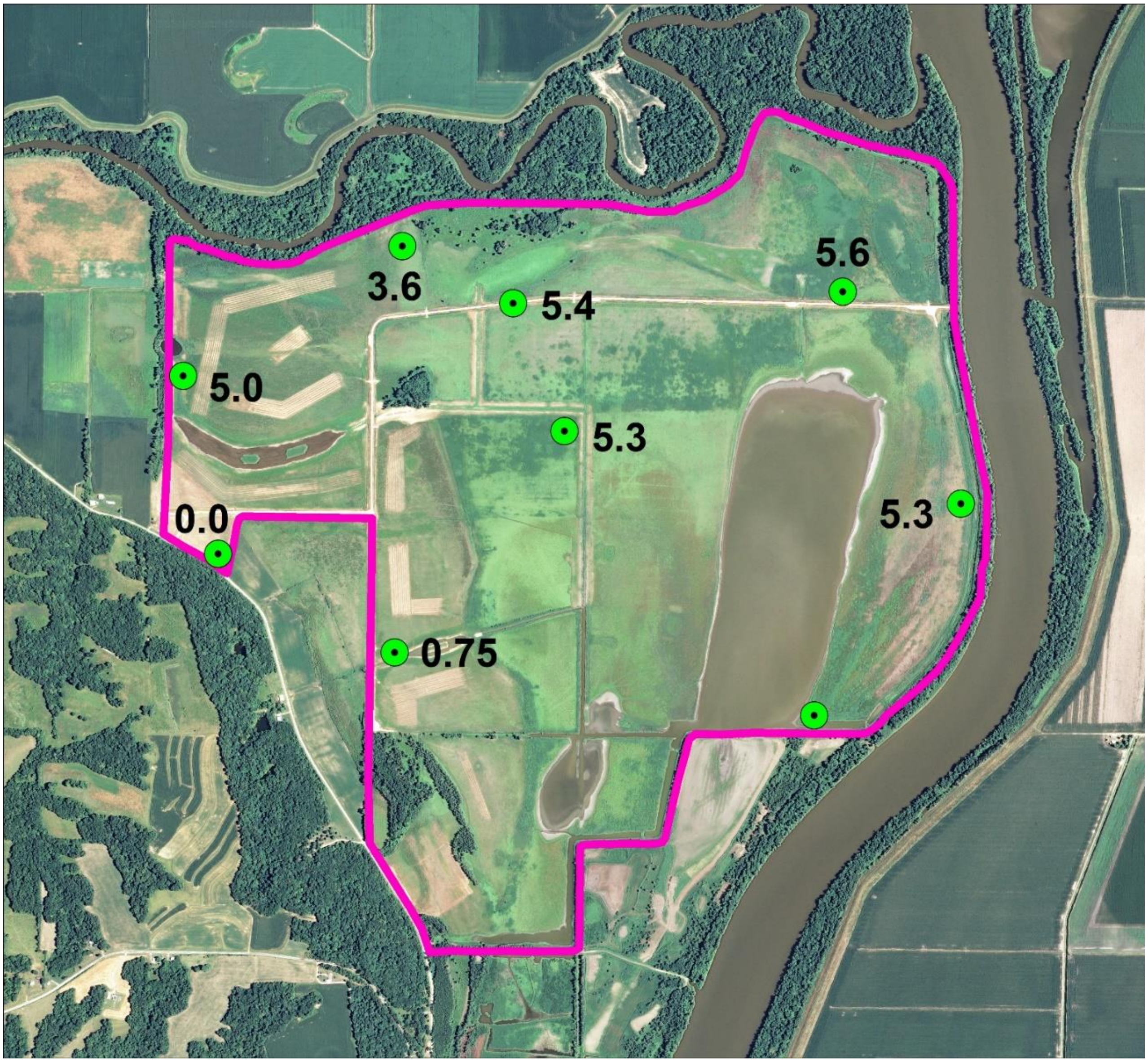


Figure 18: Site-wide network of benchmarks used in initial measurements of sedimentation rate.

Figure 19: Measuring sediment thickness over a buried ISGS benchmark.
(the arrow indicates the top of the 1” steel post)

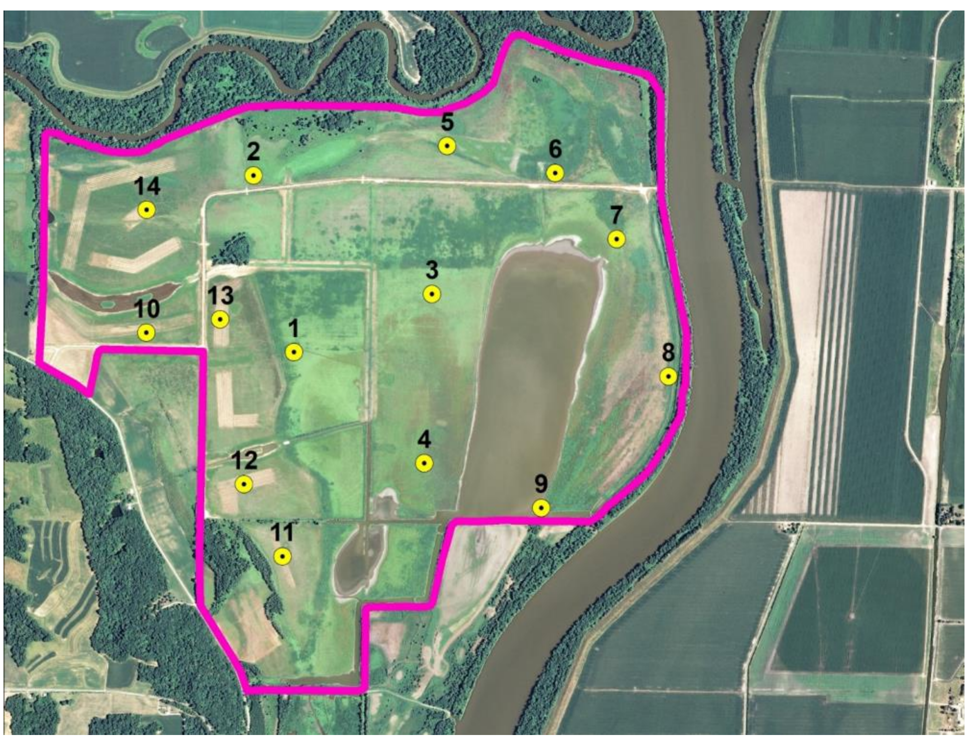


Figure 20: The network of 14 sediment stakes emplaced on site in December 2011.
(the numbers are the station identifiers)

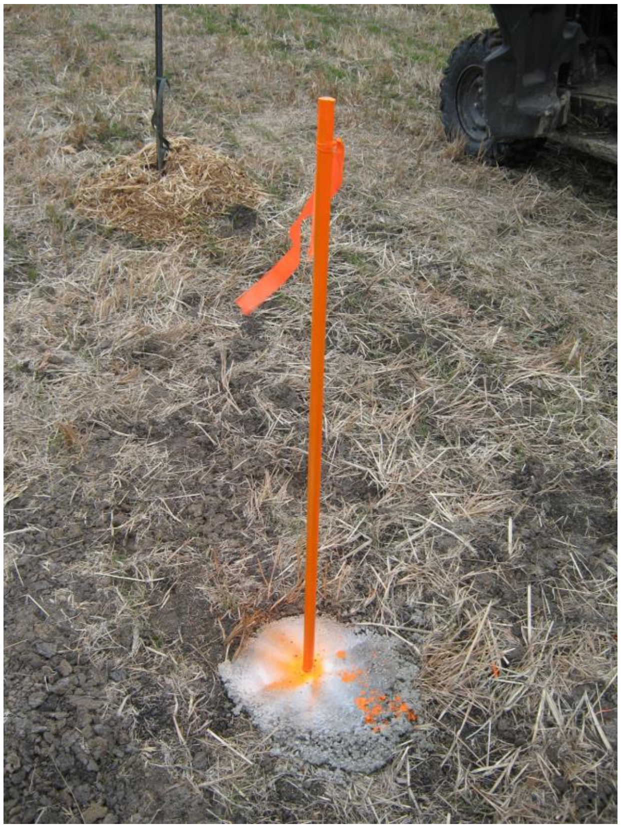


Figure 21: Preparing a stake location for a sediment depth measurement.

Figure 22: A newly finished and concreted sediment stake prior to surveying.

Figure 23: Measuring a block of sediment deposited at one of the stakes with calipers.

Results

Core Descriptions

A total of seven cores (ISWS Cores 149-155) were taken on July 8, 2004, at four locations (ISGS locations 1-4) in the backwater lakes and environs (Figure 8). Table 1 summarizes the collection particulars, locations, and purpose for each core.

Detailed material examinations and descriptions were done on August 3, 2004, for one core from Big Lake (151), Crane Lake (153) and off-lake (155), while the second Big Lake core location (150) was used for additional analyses. Radiographs (x-rays) taken of these four cores did not show any significant structures or laminae. Table 2 details the Munsell color, the presence of any mottling, the presence of plant debris, and the reaction to testing with a 2% solution of a-a' dipyridyl for the presence of reduced iron for each depth interval in the three cores (151, 153, 155). Results from the a-a' dipyridyl solution test indicate if the interval has experienced primarily anaerobic (or reducing conditions) and is a quick indicator of hydric (or wetland) soil-forming conditions. Unconfined compression strength in sediment cores is measured in tons/ft^2, and pocket penetrometer readings were taken at selected intervals in the four cores (Table 3). Percent organic carbon was also calculated and plotted for the same depth intervals in cores 150, 153 and 155 (Figure 25).

Table 1: Core summary and collection data.

Core Summary							Water	Refusal	Bed	Date core
ISGS	ISWS	Date	Core	Core	Coordinates		Depth	Depth	Surface	Examined
Location number	Core number	Collected	purpose	Location	Latitude	Longitude	(m)	(m)	Sample	8/3/2004
1	149	7/8/2004	Spare	SE Big Lake	39°57’59.235”N	90°31’13.191”W	1.28	1.68	Ponar	8/3/2004
	150	7/8/2004	Chemistry	SE Big Lake	“	“	1.28	1.46	Ponar	8/3/2004
2	151	7/8/2004	Chemistry	N Big Lake	39°58’16.715”N	90°31’11.417”W	1.31	1.31	Ponar	8/3/2004
	152	7/8/2004	Spare	N Big Lake	“	“	1.31	1.49		8/3/2004
3	153	7/8/2004	Chemistry	Crane Lake	39°57’47.125”N	90°31’49.226”W	1.07	1.07	Ponar	8/3/2004
	154	7/8/2004	Spare	Crane Lake	“	“	1.07	1.01		8/3/2004
4	155	7/8/2004	Chemistry	W of Big Lake	39°58’6.091”N	90°31’31.192”W	0.76	0.61	grab	8/3/2004

Core 150

Core 150 (Figure 11) was collected in the southeast portion of Big Lake in 1.28 m of water. The 0-10 cm interval was very fluid with abundant plant debris and a silt-clay texture. The 10-60 cm interval was more compact and coherent texture with plant material. The 60-112 cm interval was denser with iron-manganese stains and some root fragments. No sand layers were observed in the core.

Core 151

Core 151 (Figure 12) was collected in the north-central end of Big Lake in 1.31 m of water. The 0-12 cm interval was soft and fluid with no structure. The surface to 60 cm interval had some soil texture, plant debris and became denser with depth. The Munsell colors in this interval were all 10YR4 or 10YR3 with low-chroma (/2 or /1). At ~60 cm there was a change from a more uniform color to a 10YR 4/1 matrix with varying percentages of high-chroma mottling, oxidized root channels, and iron-manganese stains. From 60-97 cm the materials were much denser. A pellet of suspected lead shot was observed in the radiograph at a depth of 20 cm. Testing with a-a' dipyridyl indicated the presence of reduced iron from surface to 97 cm, with a weak positive at 97-110 cm.

Core 153

Core 153 (Figure 13) was collected in 1.07 m of water in the center of Crane Lake. The 0-30 cm interval had a uniform texture with root and plant fragments. The Munsell colors in this interval were all 10YR3/1 or 10YR2/1 (low-chroma). At ~30 cm, there was a change to increasingly denser materials with depth down to the end at 82 cm. From 30-82 cm, matrix colors remained in the 10YR4 and 10YR3 range but the materials exhibited varying high-chroma mottling and iron-manganese stains. Testing with a-a' dipyridyl indicated the presence of reduced iron from surface to 60 cm, with a weak positive at 60-72 cm and a negative at 72-82 cm.

Core 155

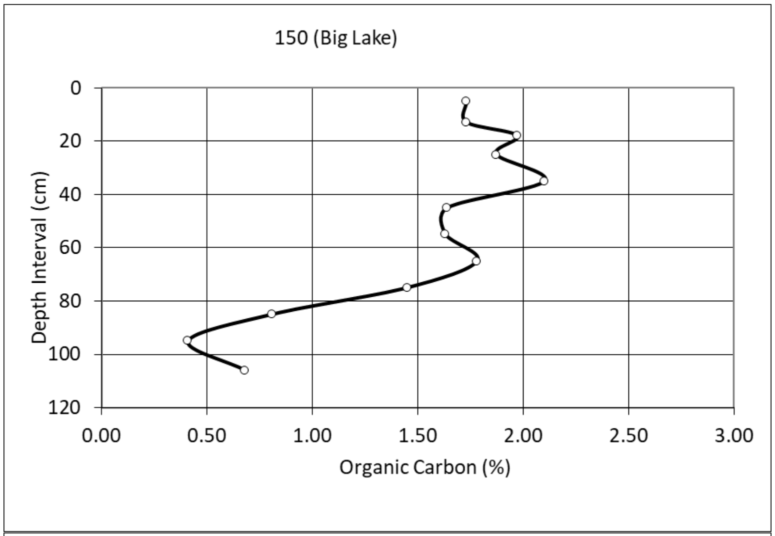
Core 155 (Figure 14) was collected in an off-lake area west of Big Lake in 0.76 m of water. The 0-20 cm interval was a silty clay texture with abundant plant matter. The Munsell colors in this interval were all 10YR3/1 or 10YR3/2 (low-chroma). At 20-42 cm, there was a change to increasingly dense materials with depth. From 20-42 cm, matrix colors remained at 10YR3/1 (low-chroma), but the materials exhibited varying high-chroma mottling from 20-25 cm and again at 33-42 cm. The 20-42 cm interval also exhibited iron-manganese stains. A pellet of suspected lead shot was observed in the radiograph at a depth of 4.0 cm. Testing with a-a' dipyridyl indicated the presence of reduced iron only from surface to 5 cm, with a weak positive only along root channels at 5-10 cm. The remainder of the profile was negative for reduced iron from 15-42 cm.

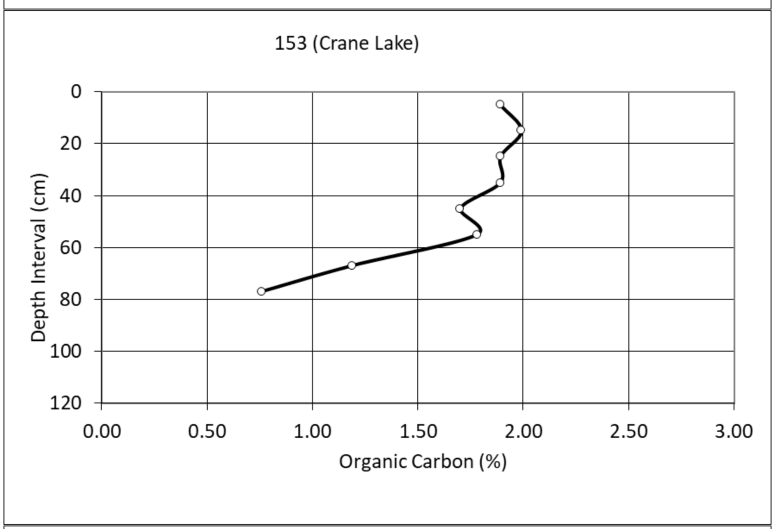
Table 2: Core descriptions for cores 151, 153, and 155.

ISWS Core ID number (+interval)	Depth Interval (cm)	a-a' dipyridyl (+ve/-ve)	Munsell color (matrix)	Munsell color (mottles)	notes
Core 151					
151-1	0-5	+	10YR 3/1	no mottles	plant debris
151-2	5-10	+	10YR 3/1	no mottles	plant debris
151-3	10-15	+	10YR 3/1	no mottles	plant debris
151-4	15-20	+	10YR 3/1	no mottles	plant debris
151-5	20-30	+	10YR 3/1	no mottles	plant debris
151-6	30-40	+	10YR 4/1	no mottles	plant debris
151-7	40-50	+	10YR 3/2	no mottles	plant debris
151-8	50-60	+	10YR 3/2	no mottles	plant debris
151-9	60-70	+	10YR 4/1	10YR 4/6	
151-10	70-80	+	10YR 4/1	10YR 3/6	oxidized root channels
151-11	80-97	+	10YR 4/1	10YR 3/6	mottles 30%
151-B	97-110	weak+	10YR 4/1	7.5YR 5/8	mottles >50%, oxidized root channels
Core 153					
153-1	0-10	+	10YR 2/1	no mottles	plant debris
153-2	10-20	+	10YR 3/1	no mottles	plant debris
153-3	20-30	+	10YR 3/1	no mottles	plant debris
153-4	30-40	+	10YR 3/1	7.5YR 4/6	
153-5	40-50	+	10YR 3/1	10YR 3/6	
153-6	50-60	+	10YR 3/1	5YR 4/6	
153-7	60-72	weak+	10YR 4/1	10YR 3/6	
153-B	72-82	-	10YR 3/2	5YR 5/8	
Core 155					
155-1	0-5	+	10YR 3/1	no mottles	plant debris
155-2	5-10	weak+	10YR 3/2	no mottles	a-a' dipyridyl, +ve only along roots, plant debris
155-3	10-15	-	10YR 3/2	no mottles	@12cm, blocky soil texture (peds), plant debris
155-4	15-20	-	10YR 3/2	no mottles	plant debris
155-5	20-25	-	10YR 3/1	10YR 3/3	mottles 10%
155-6	25-33	-	10YR 3/1	no mottles	
155-B	33-42	-	10YR 3/1	10YR 4/6	mottles 50%

Table 3: Pocket penetrometer readings at select intervals in the cores.

Core ID	Surface	0.25 ft (8 cm)	0.5 ft (15 cm)	1.0 ft (30 cm)	1.5 ft (46 cm)	2.0 ft (61 cm)	2.5 ft (76 cm)	3.0 ft (91 cm)	Base
150	0.0			0.09		0.16		0.28	0.75
151	0.0				0.09	0.17	0.28		
153	0.0			0.21		0.23			0.75
155	0.0	0.15	0.11	0.28					





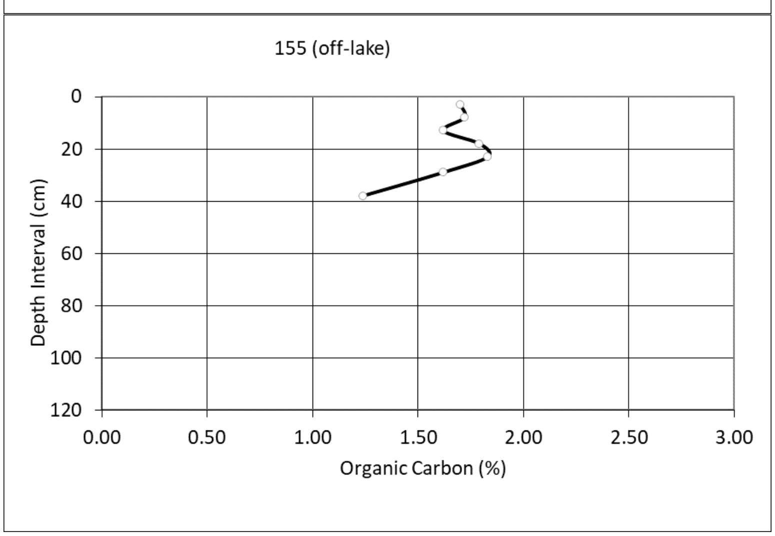


Figure 24: Plots of organic carbon versus depth for cores 150, 153, and 155.

Air-Dried Loss and Wet and Dry Densities

On average, the basal materials in the three lake cores lost roughly 24% of their mass after oven drying at 110°C. The dry density of these materials averaged roughly 1.39 g/cm^3. At the other end of the column, the relatively fresh lake sediments lost roughly 47.4% of their mass after oven drying at 110°C. The dry density of these materials averaged roughly 0.97 g/cm^3. However, the progression from the more water-laden, less-dense, surficial samples to the drier, more-dense samples at depth was not a uniform progression. There were some reversals and perturbations in the profile. The off-lake area had a dry density at surface of 1.31 g/cm^3, which was almost as dense as the mean dry density of the lake cores at depth. The 110°C loss at depth was 23.7% and showed a similar moisture content to the lake cores. Although, the surficial materials held less moisture at 32.1% loss versus a range of 41-55% in the lake cores. These data are summarized in Table 4. Paired plots are provided of wet and dry density versus depth and air dried loss and 110°C loss versus depth are provided for cores 150 (Figure 25), core 151 (Figure 26), core 153 (Figure 27) and core 155 (Figure 28).

Sedimentation Rate Estimates Using ^{137}Cs

In Big Lake core 150, the peak ^{137}Cs activity came at a depth of 20-30 cm. Taking the midpoint of this depth interval (25 cm) and using to the accepted year of peak atmospheric deposition of ^{137}Cs (1963), this analysis of the data would yield an average deposition rate of 0.61 cm/yr from 1963 until this core was collected in 2004. Lower down in the core, the first depth interval to show a ^{137}Cs count above the method detection limit (0.002 mBq/g) should dictate the position in the sedimentation record when fallout from the testing of nuclear weapons in the atmosphere began to be deposited in significant quantities or the “onset” of ^{137}Cs activity (accepted year is 1954). In core 150, this count came at a depth of 30-40 cm. Using the midpoint of this depth interval (35 cm), the secondary deposition rate for this core is 0.70 cm/yr from 1954 to 2004. This secondary rate is similar to the first rate and acts as a check on the uniformity of deposition rates over the time/depth range of the two samples.

In Big Lake core 151, the peak ^{137}Cs activity also came at a depth of 20-30 cm (midpoint 25 cm) and the onset of ^{137}Cs activity also came at 30-40 cm (midpoint 35 cm), yielding the same average deposition rates of 0.61 and 0.70 cm/yr as in core 150 (from 1963-2004 and 1954-2004, respectively). Once again, in Crane Lake core 153, the peak ^{137}Cs activity came at a depth of 20-30 cm (midpoint 25 cm) and the onset of ^{137}Cs activity also came at 30-40 cm (midpoint 35 cm), yielding the same average deposition rates of 0.61 and 0.70 cm/yr as in cores 150 and 151 (from 1963-2004 and 1954-2004, respectively).

The off-lake core (155) was also analyzed in this manner, despite the shallow depth and limited recovery (42 cm). The peak ^{137}Cs activity came at a depth of only 0-5 cm (midpoint 2.5 cm) and the onset of ^{137}Cs activity came at 15-20 cm (midpoint 17.5 cm). This area was witnessed by ISGS to have been routinely row-cropped right to the Big Lake shoreline in the period from 2000-2005 and was likely historically farmed as well. Farm equipment overturns soils to depths greater than 20 cm so it is likely that the ^{137}Cs record is not meaningful at this location for calculating deposition rates.

The degree of agreement between the rates calculated in all three lake cores (150, 151 and 153) indicates that sedimentation rates are quite uniform geographically in the lake basins on-site and have a fairly consistent rate at least back to 1954. Table 5 shows the calculations to assign approximate dates to the depth intervals using the results from core 150 as an example. Figure 29 shows a graph of ^{137}Cs activity versus depth for all three lake cores, while Figure 30 shows ^{137}Cs activity versus depth for the (likely overturned) materials at core location 155.

The exact location of the 1954 horizon, or the "onset" of measurable radioactive fallout from atmospheric testing, is less distinct than the 1963 horizon of the "peak" of nuclear weapon testing fallout, as less ^{137}Cs is present in these deeper sediments due to radioactive decay (more than one half life has passed; Cahill et al., 2008). As a result and compounding this problem, the first measurable level of ^{137}Cs counts (1954 marker) may be very close to the method detection limit. For this reason, the 1963 peak ^{137}Cs activity reading was relied upon for this study to assign mean deposition rates on the site.

Grain Size Analysis

The grain size results are shown in Appendix A Table A1. The distributions represented a typical profile of backwater alluvial sediments. The 24 total samples analyzed from both cores had almost no sand (averaged ~0.4 %) and averaged ~51.3% silt and ~48.7% clay.

When the approximate dates from the preceding radiometric analysis of core 150 were applied to convert the depth intervals to years, a pattern emerged (Figure 32). In core 150, the group of seven finer-grained profiles, which represented a depth range of 0-60 cm, corresponded to a year range from roughly 1996 to 1914. While the second group of four samples, from a depth range of 60 to 112 cm, had dates of 1897 to 1830. When the approximate ^{137}Cs dates from the preceding radiometric analysis of core 151 were again applied to convert the depth intervals to years, a pattern emerged again (Figure 32). In core 151, the group of seven finer-grained profiles, which represented a depth range of 0-50 cm, corresponded to a year range from roughly 2000 to 1930. The sample from a depth range of 50-60 cm (^{137}Cs age of 1914) showed a perturbation from the more consistent previous profiles (red line on plot). While the final group of four coarser samples, representing a depth range of 60 to 110 cm, had dates of 1897 to 1834.

In core 150, the younger, finer-grained samples (1996-1914) averaged 46% silt and 54% clay, while the coarser, older sediments (1897-1830) averaged 64% silt and 36% clay, marking a change in depositional character of the southeast portion of the lake basin at some point between 1897 and 1914 (shown graphically in Figure 33). Similarly in core 151, the younger, finer-grained samples (2000-1930) averaged 45% silt and 55% clay, while the coarser, older sediments (1897-1834) averaged 58% silt and 42% clay, marking a change in depositional character of the north-central portion of the lake basin at some point between about 1897 and 1914.

Analyses of Inorganic Chemical Constituents

The results of these analyses from the contract lab for core 150 focused on heavy metals and are provided in Appendix A Table A2. The full set of results, including 60 analytes for cores 150, 153, and 155 as well as replicates and NIST certified reference materials for QA/QC, are provided in Appendix A Table A3. A detailed discussion of the full set of sediment chemistry results is beyond the scope of this report.

One metal for which the timing of appearance in the environment is well known is lead, because of its release from the combustion of tetraethyl lead-containing automotive fuels. The results of applying the lead concentrations from the XRF analyses to the Cs-derived dates from Big Lake core 150 is presented as a plot of lead concentration versus depth on the site (Figure 34). The sediments have generally low lead concentrations until about 1914, prior to the widespread use of automobiles. Concentrations double, and then triple, from the introduction of automotive lead in the 1920s, peaking in about 1947, corresponding with the post-war auto boom. Lead in the sediments then reduces with the introduction of pollution-control measures on vehicles and the eventual introduction of unleaded fuel in the 1970s. These lead values provide another line of evidence to support ^{137}Cs-derived mean deposition rates at least as far back as the early 1900s.

Table 4: Air-dried loss, 110°C loss, and wet and dry densities for cores 150, 151, 153, and 155.

ISGS Core ID number	Depth interval (cm)	Mid-point (cm)	Wet density‡ (g/cm^3)	Dry density‡ (g/cm^3)	Air-dried loss (%)	110°C loss (%)
150-B*	100-112	106.0	1.60	1.41	17.3	22.2
150-11	90-100	95.0	1.95	1.67	20.0	22.7
150-10	80-90	85.0	1.65	1.43	21.3	23.2
150-9	70-80	75.0	1.79	1.45	23.3	28.6
150-8	60-70	65.0	1.64	1.33	26.6	29.1
150-7	50-60	55.0	1.63	1.29	28.0	31.4
150-6	40-50	45.0	1.76	1.44	27.9	31.4
150-5	30-40	35.0	1.68	1.31	31.2	32.7
150-4	20-30	25.0	1.29	1.03	32.8	36.0
150-3	15-20	17.5	1.66	1.35	32.1	34.0
150-2	10-15	12.5	1.61	1.28	33.6	36.1
150-1	0-10	5.0	1.40	0.97	40.9	45.0
151-B	97-110	103.5	1.59	1.36	24.8	25.0
151-11	80-97	88.5	1.72	1.47	24.4	25.4
151-10	70-80	75.0	1.60	1.35	25.8	26.7
151-9	60-70	65.0	1.50	1.21	28.1	27.8
151-8	50-60	55.0	1.76	1.43	28.8	29.8
151-7	40-50	45.0	1.63	1.26	33.0	35.7
151-6	30-40	45.0	1.56	1.21	35.3	38.3
151-5	20-30	35.0	1.28	0.99	36.0	38.7
151-4	15-20	25.0	1.40	1.03	41.2	41.3
151-3	10-15	17.5	1.25	0.92	45.0	46.8
151-2	5-10	12.5	1.13	0.81	50.1	51.0
151-1	0-5	2.5	1.32	0.92	53.9	55.5
153-B	72-82	77.0	1.64	1.40	20.7	24.8
153-7	60-72	66.0	1.88	1.62	24.4	26.7
153-6	50-60	55.0	1.63	1.28	29.9	35.2
153-5	40-50	45.0	1.49	1.20	30.2	33.6
153-4	30-40	35.0	1.63	1.34	29.9	31.8
153-3	20-30	25.0	1.63	1.33	29.6	34.2
153-2	10-20	15.0	1.39	1.11	34.3	37.8
153-1	0-10	5.0	1.32	1.03	39.3	41.6
155-B	33-42	37.5	1.65	1.43	21.8	23.7
155-6	25-33	29.0	1.75	1.47	27.0	28.6
155-5	20-25	22.5	1.61	1.36	28.3	28.5
155-4	15-20	17.5	1.64	1.38	30.1	31.6
155-3	10-15	12.5	1.49	1.27	30.6	31.0
155-2	5-10	7.5	1.63	1.33	28.0	30.1
155-1	0-5	2.5	1.59	1.31	31.2	32.1

*B = Base of cores extracted from the core catcher in the field.

‡Density calculations may be subject to inaccuracies due to weight loss in storage bag.

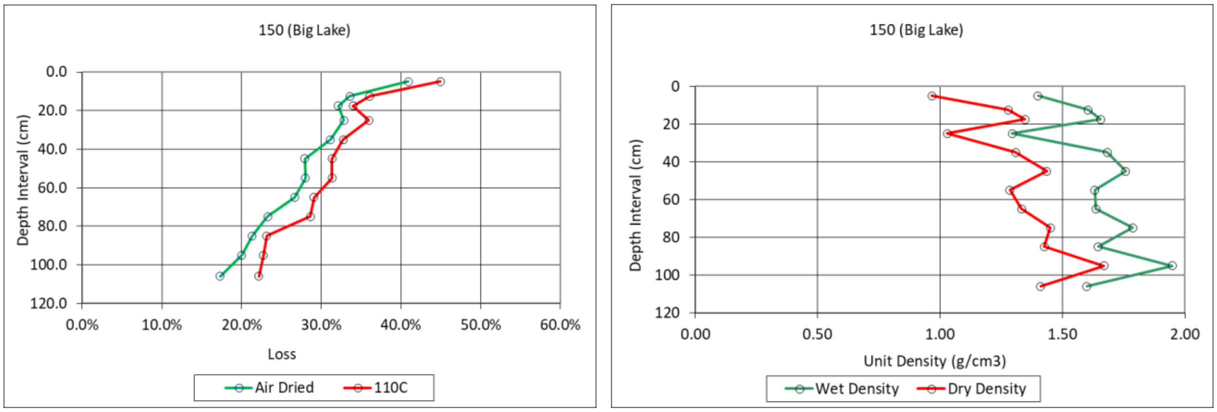


Figure 25: Plots of air-dried and 110°C loss and wet and dry density versus depth for core 150.

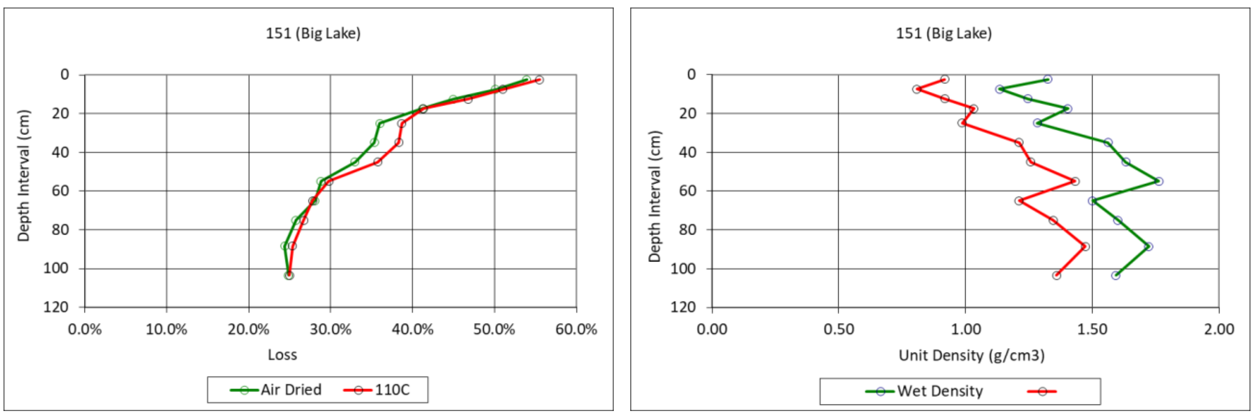


Figure 26: Plots of air-dried and 110°C loss and wet and dry density versus depth for core 151.

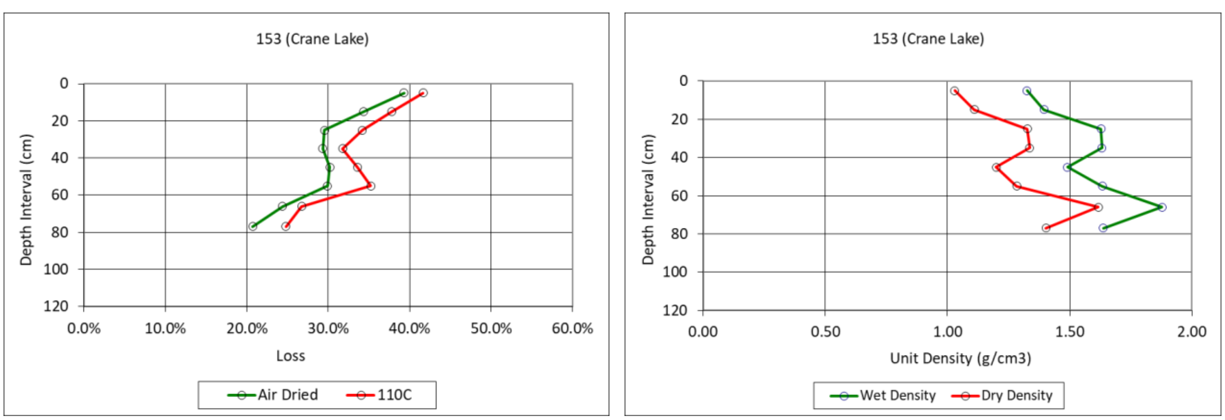


Figure 27: Plots of air-dried and 110°C loss and wet and dry density versus depth for core 153.

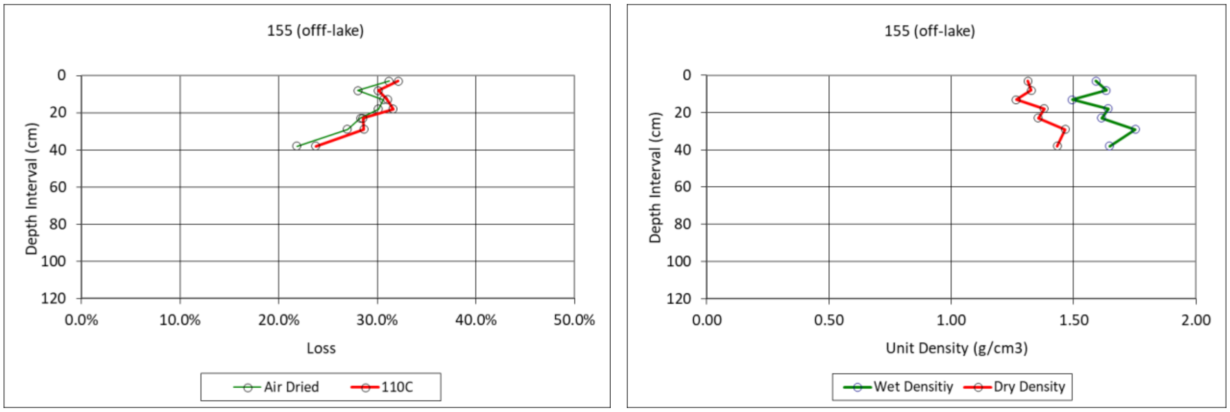


Figure 28: Plots of air-dried and 110°C loss and wet and dry density versus depth for core 155.

Table 5: Example ^{137}Cs dating calculations for Core 150 (Big Lake).

Core 150 – Big Lake		rate (cm/yr)	Year			
Cs-137 peak activity: 25 cm		0.61	1963			
Cs-137 onset (measurable): 35cm		0.70	1954			
Sample	Depth range (cm)	Midpoint (cm)	Cs-137	Peak activity age (Cs-137)	Onset activity age (Cs-137)	Cs-137 activity (mBq/g)*
150-1	0-10	5		1996	1997	0.00447
150-2	10-15	12.5		1984	1986	0.00862
150-3	15-20	17.5		1975	1979	0.01415
150-4	20-30	**25**	**Peak activity**	**1963**	1968	0.02544
150-5	30-40	**35**	**Cs onset**	1947	**1954**	0.01306
150-6	40-50	45	no activity	1930	1940	0.00105
150-7	50-60	55	no activity	1914	1925	0.00098
150-8	60-70	65		1897	1911	NS
150-9	70-80	75		1881	1897	NS
150-10	80-90	85		1865	1883	NS
150-11	90-100	95		1848	1868	NS
150-B	100-112	106		1830	1853	NS

*compared to an NIST std

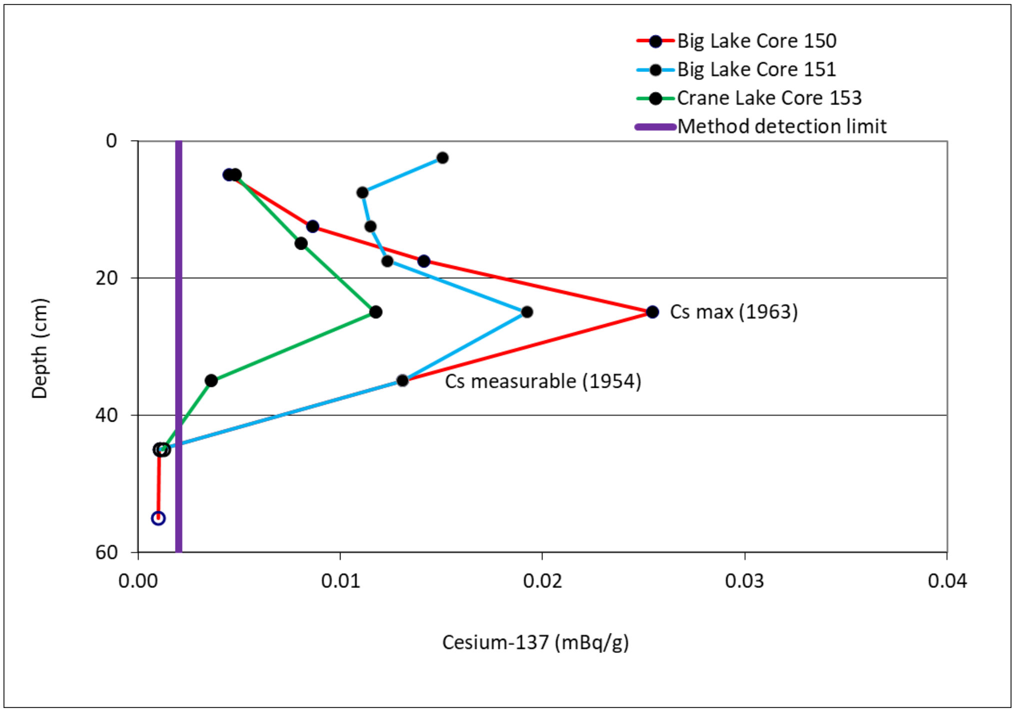


Figure 29: ^{137}Cs activity versus depth for Big Lake and Crane Lake cores.

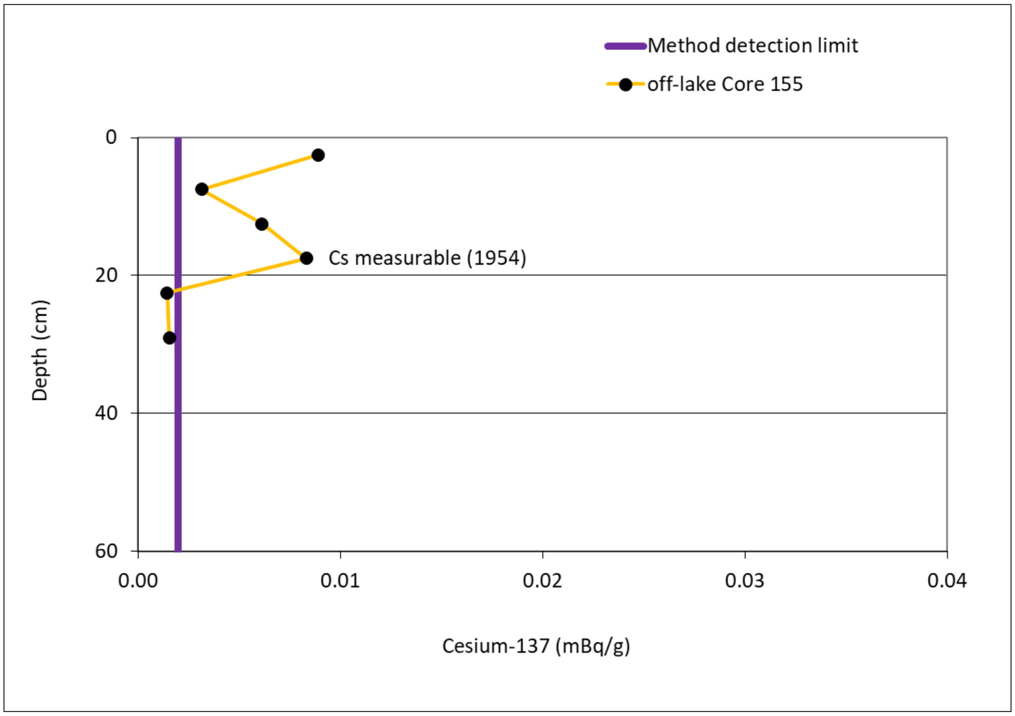


Figure 30: ^{137}Cs activity versus depth for the off-lake core (155).

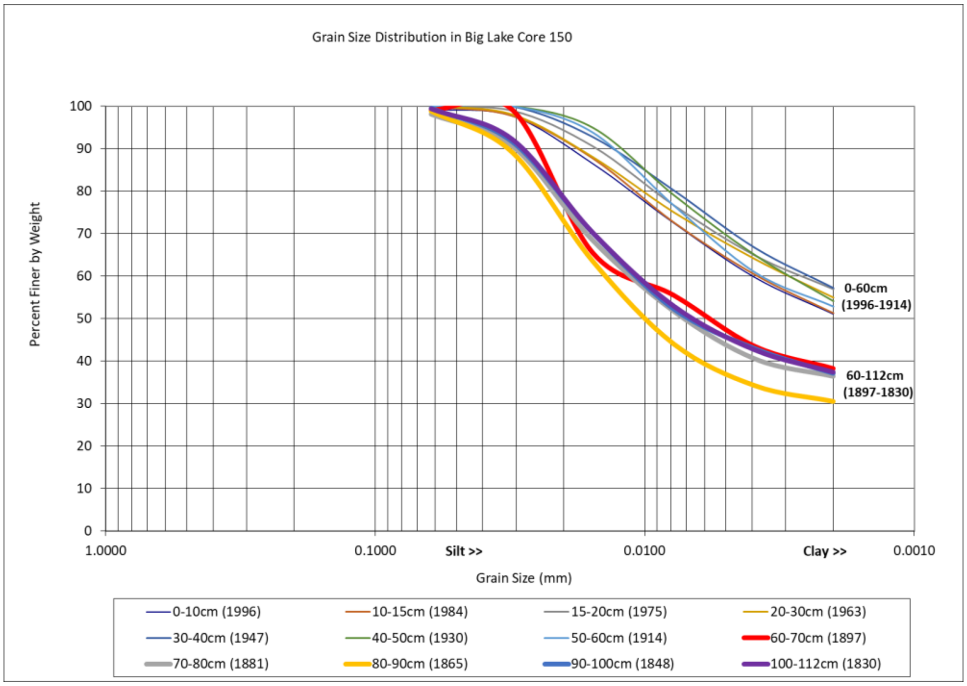


Figure 31: Grain size distribution plots for core 150 (Big Lake).

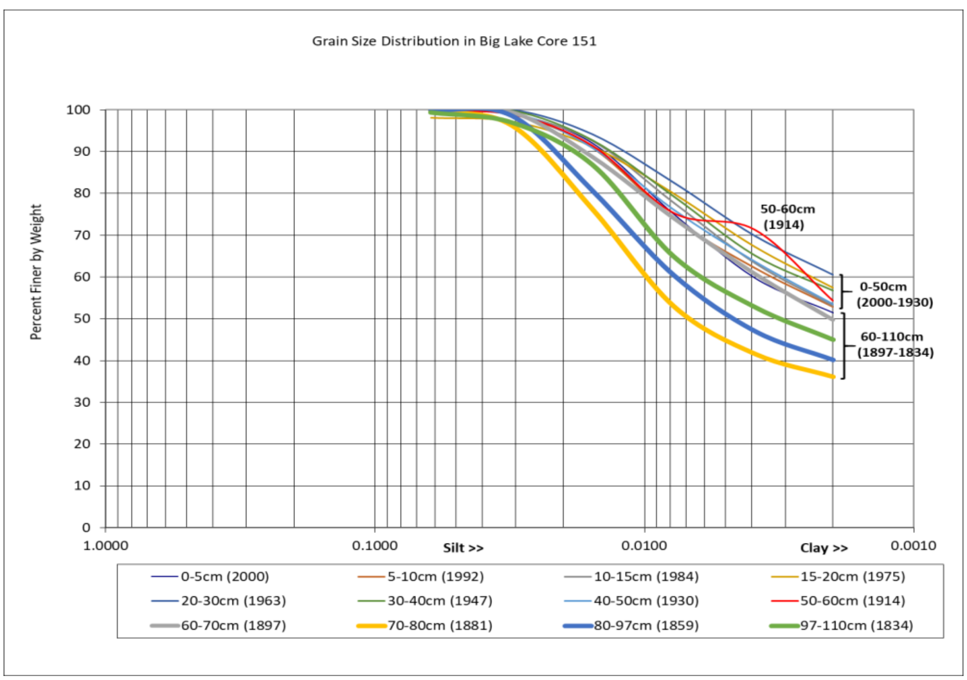


Figure 32: Grain size distribution plots for core 151 (Big Lake).

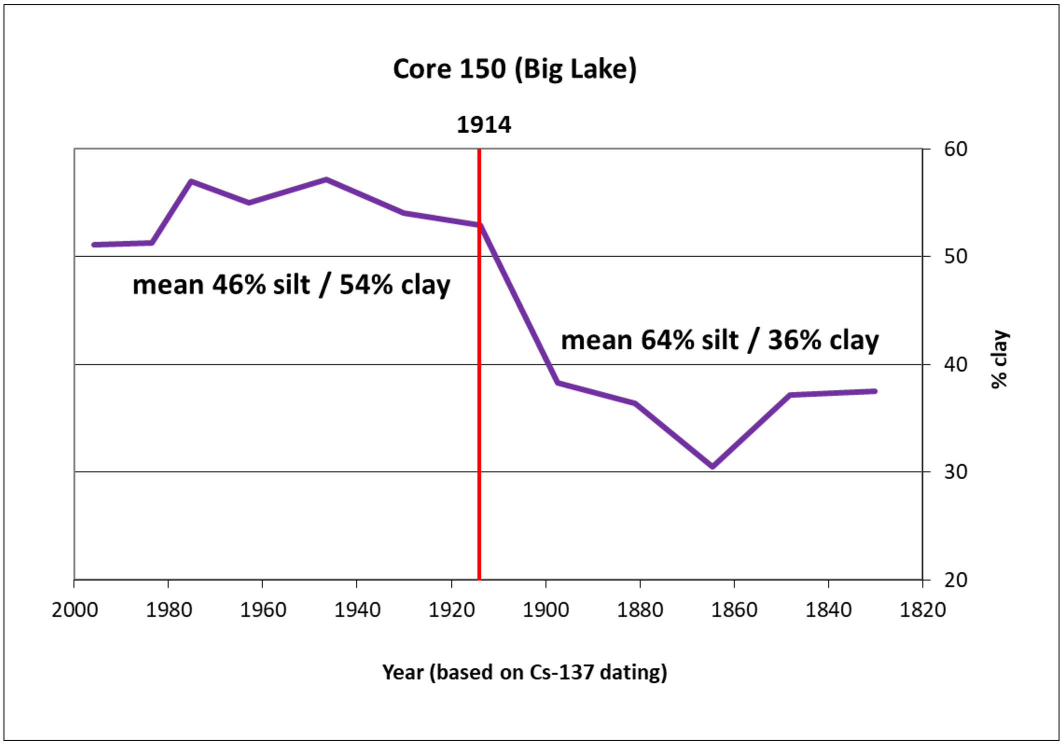


Figure 33: Shift in silt / clay percentage in core 150 (Big Lake).

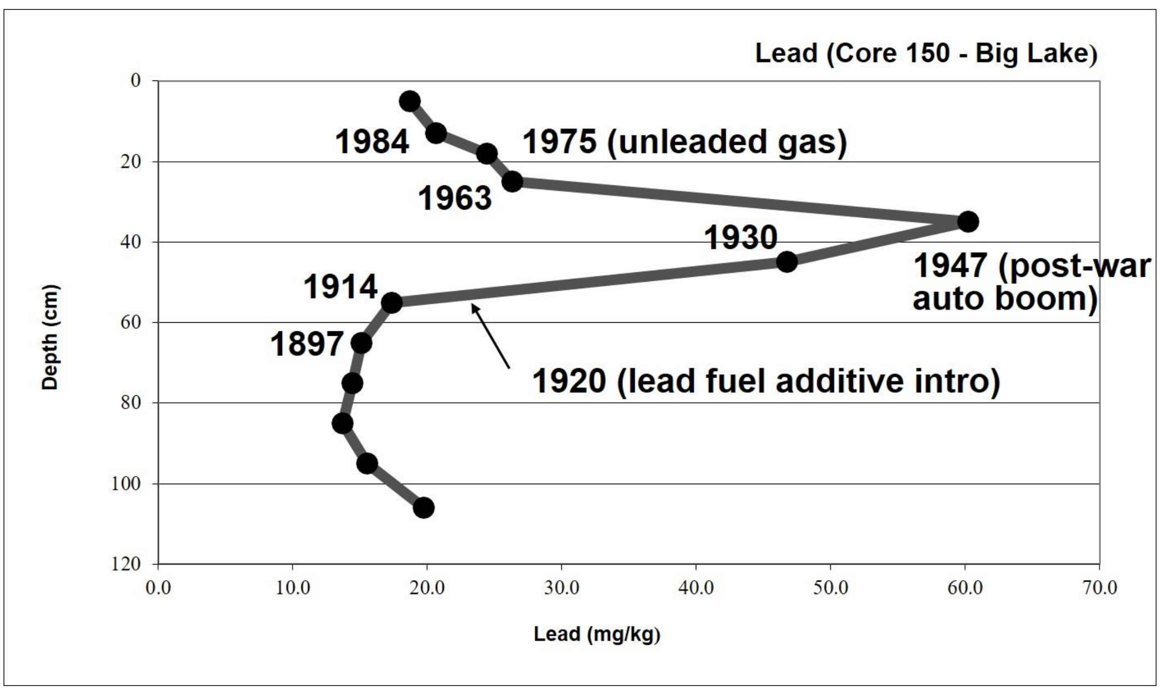


Figure 34: Lead (ICP-MS) versus depth in Big Lake core 150.

Lakebed Survey

In total, 326 XYZ data points were obtained from 12 transects across Big Lake (Figure 17). These data were then contoured using ArcMap and at an interval of 10 cm (Figure 35). The ArcMap software also was used to create cross-section (bed profiles) by slicing the map in the northern portion of the lake (Transect W9-E9; Figure 36) and at the southern end of the lake (Transect W1-E1; Figure 36). The saucer-shaped profile of a typical backwater lake is apparent in the northern transect, while the southern transect clearly shows the lakebed scour adjacent to the point where the 2002 levee breach occurred. Calculated from the ArcMap generated topographic model (DTM) of the lake bottom, the lake has a surface area of 195 acres, a mean depth of 0.83 meters, and a volume of 534 acre/ft. This last number was generated for the purpose of calculating the expected lifespan of the lake via on-going sedimentation rates.

Sediment Depths from the Benchmark Measurements

The ISGS benchmarks provided a useful interim method of measuring sediment depth. Thicknesses at the nine locations ranged from 0.0 cm, where the steel post was exposed at a location along the west site margin that did not flood during the 2002-2009 measurement period, to 5.6 cm at a location in the northeast portion of the site that routinely floods and is often inundated for long periods after flood events (Figure 20). At one benchmark location in the southwest corner of the site and near the Big Lake margin, no sediment was measured, likely due to wave action. The mean depth of sediment measured site-wide at the nine locations was 3.87 cm, which accumulated over 7.21 years (May 13, 2002 to July 27, 2009), yielding a mean sedimentation rate of 0.54 cm/year for that period.

Sediment Depths from the Stake Network

The beginning date for sediment accumulation measurement was the stake emplacement date of December 13, 2011. The sediment depths at the stakes were then measured on October 24, 2013, September 3, 2015, and October 17, 2017. Measurements were taken from all 14 stakes on October 24, 2013, and showed sediment depths ranging from 0.2 to 6.2 cm with a mean depth of 2.35 cm. This depth, divided over the 1.86-year period between reads, yields an average site-wide deposition rate of 1.26 cm/yr (Figure 37).

Measurements taken on the September 3, 2015, visit had 11 of the 14 stakes accessible for readings. Six stakes showed increases in sediment depth from the last reading, three showed similar readings to 2013 (within the +/- 3.0 mm measurement error), and two showed some sediment removal (or perhaps consolidation). The mean depth at the measured stakes was 2.84 cm. This depth, divided over the 3.72-year period between reads, yields an average site-wide deposition rate of 0.76 cm/yr (Figure 38).

Measurements taken on the October 17, 2017, visit had 12 of the 14 stakes accessible for readings. Four stakes showed increases in sediment depth from the last reading, four showed similar readings to 2013 (within the +/- 3.0 mm measurement error), and four showed some sediment removal (or perhaps consolidation). The mean depth at the measured stakes was 3.53 cm. This depth, divided over the 5.8-year period between reads, yields an average site-wide deposition rate of 0.61 cm/yr (Figure 39). The progression of sediment deposition on-site from 2011 to years 2013, 2015, and 2017 is presented with a gradient of color representing sediment thickness in Figures 37-39.

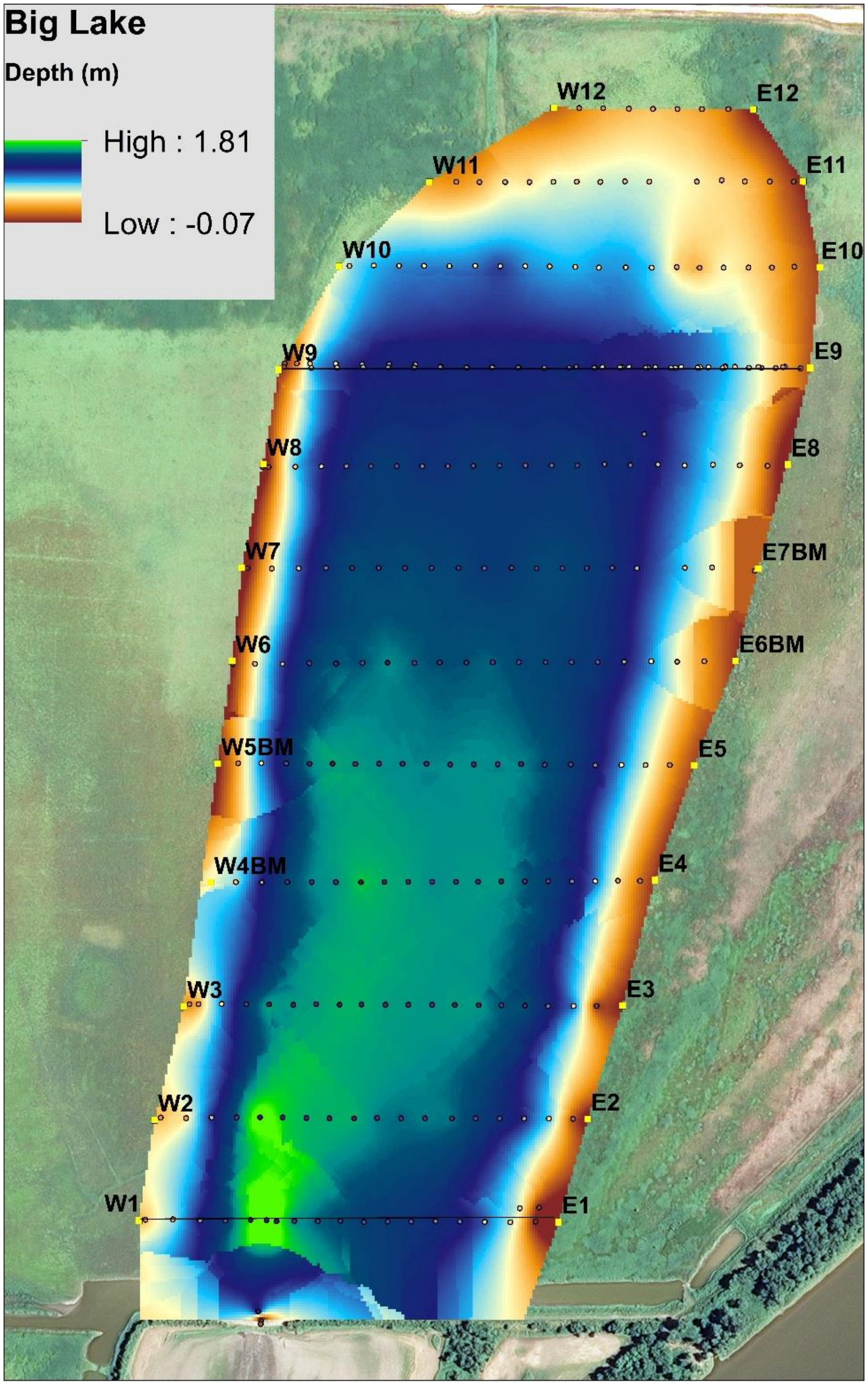
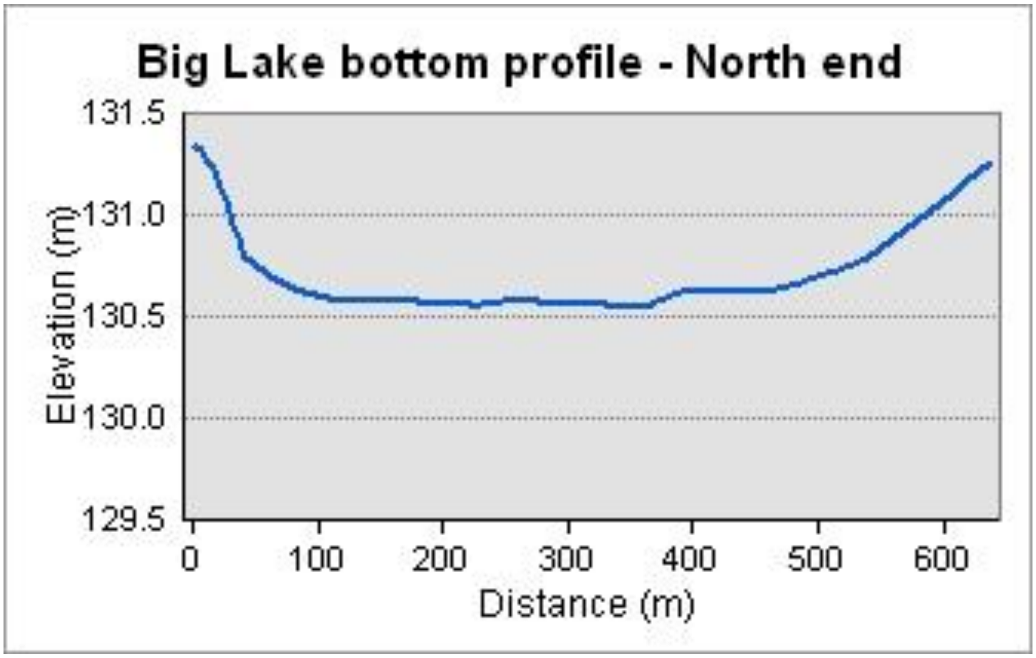
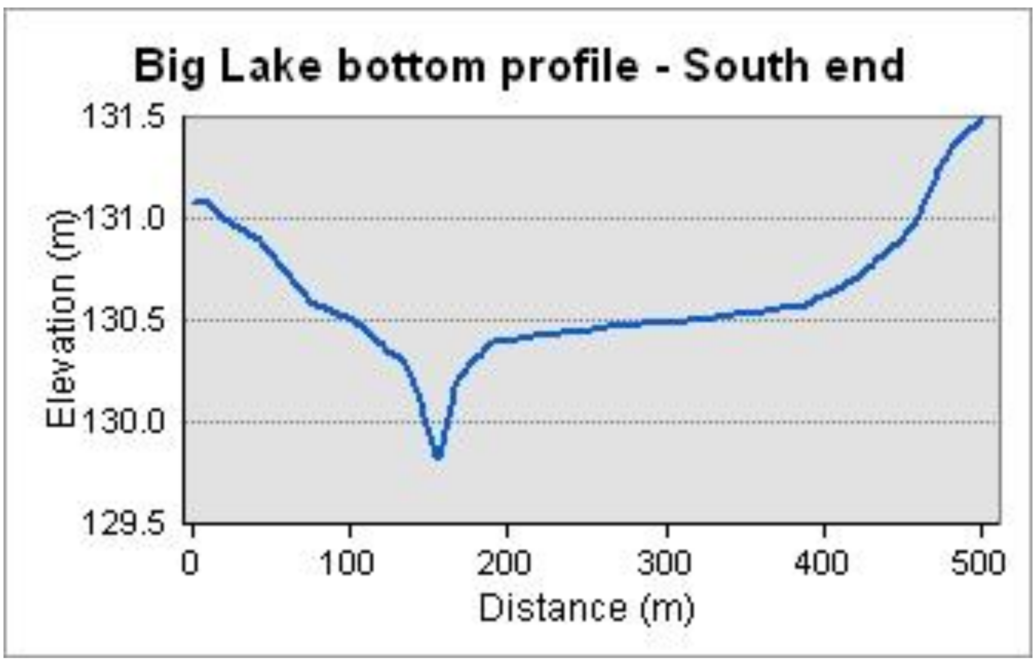


Figure 35: Big Lake contoured at a 10 cm interval with ArcMap.



A. Cross section 9 from point W9 to E9 (see Figure 35)



B. Cross section 1 from point W1 to E1 (see Figure 35)

Figure 36: Big Lake cross-sections at north and south end.

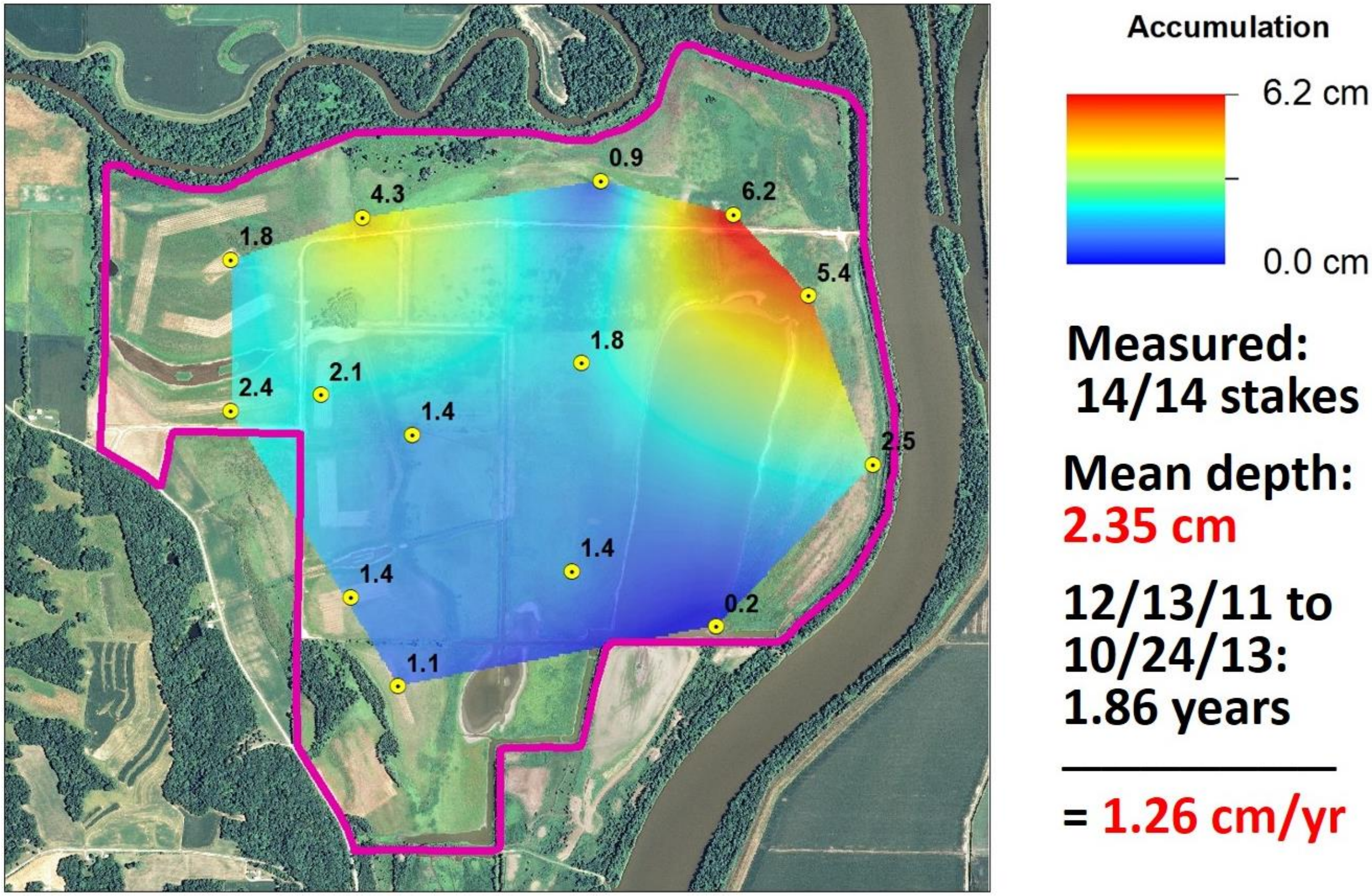


Figure 37: Sediment depths measured at stake network on site from 2011 to 2013.

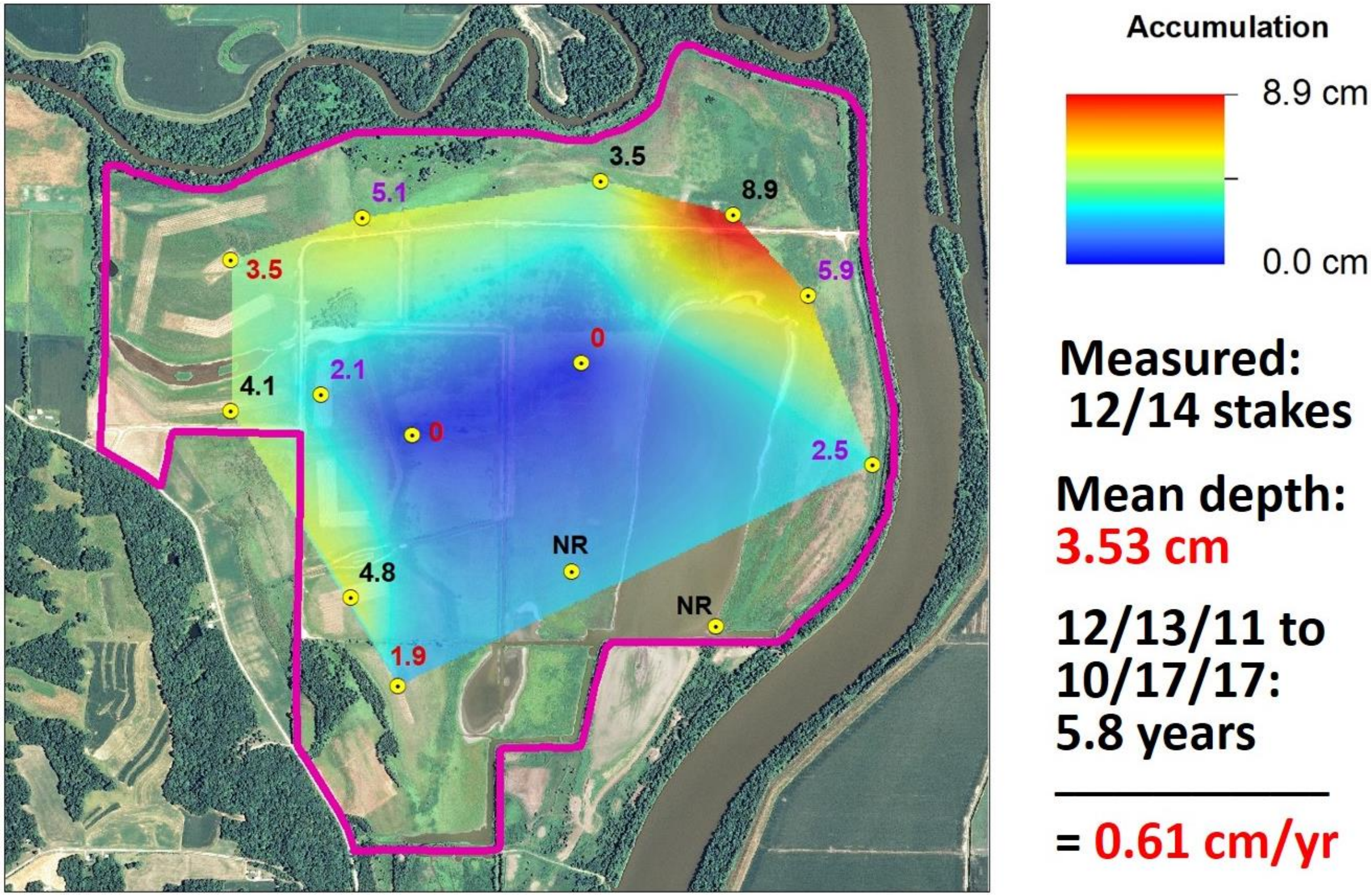


Figure 38: Sediment depths measured at stake network on site from 2011 to 2015.

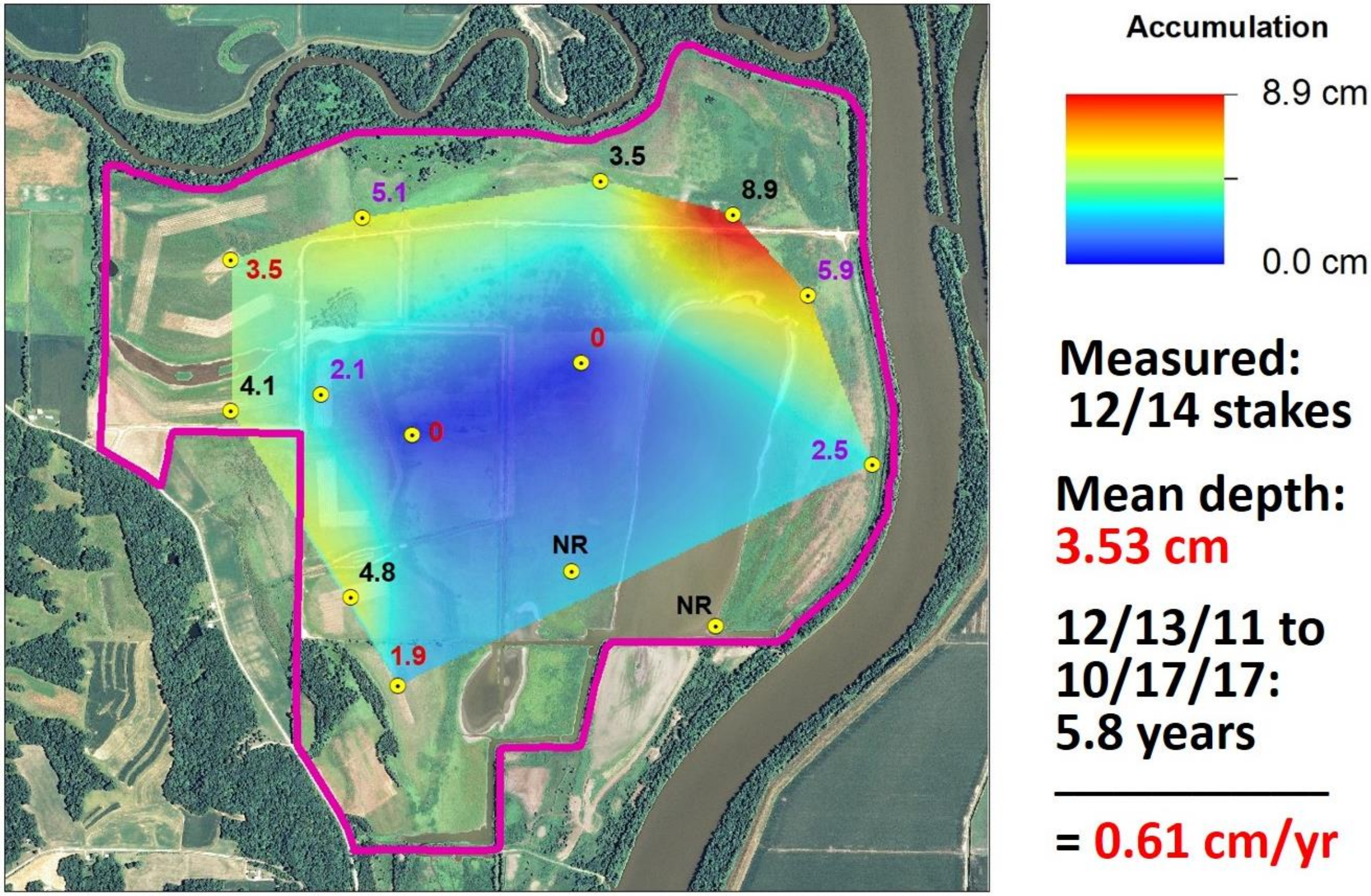


Figure 39: Sediment depths measured at stake network on site from 2011 to 2017.

Discussion

Comparison of Deposition Rates to Other Illinois River Backwater Lakes

Illinois River backwater deposition rates from the identical vibracoring method and ^{137}Cs dating methodology were presented by Cahill et al. (2008). Sedimentation rates were determined from a total of 12 locations in backwater lakes along the Illinois River, all of which were directly connected to the main river channel. The rates using the 1963 ^{137}Cs peak activity marker ranged from 0.4 cm/yr to 1.9 cm/yr with an average of 1.04 cm/yr. The rates using the 1954 onset of activity marker ranged from 0.7 to 2.0 cm/yr with an average of 1.25 cm/yr.

The rates determined for Big Lake in this study (0.61 and 0.70 cm/yr) are of the same magnitude as those in the 2008 study by Cahill et al., and it makes sense that the rates should be lower in a leveed-off lake (Big Lake) versus other lakes open to the river. In this case, the ^{137}Cs deposition rates for Big Lake are about 56-59% of the rates in the open lakes, and the ratio between the 1963 and 1954 rates are comparable at 0.87 (this study) and 0.83 (open lake study). The rates from both studies also compare very well with those determined by the USACE (2003) for the time period of 1903 to 2001 for 4 of the same 12 cored locations using traditional bathymetric survey techniques (Cahill et al., 2008). The rates determined in that study ranged from 0.5 to 1.0 cm/yr.

Depositional History from Analysis of Cores

In general, these backwater lakebed materials appeared to consist of very poorly consolidated fine-grained materials (silts and clays, minimal sand, with no apparent shells, sand lenses or any distinct laminations) and low bearing strength in the upper portions of the cores, becoming progressively more compact with depth. In general, no structures were visible that resembled annual or event-related laminations (such as varves).

It is possible that wave action in the shallow lake, coupled with possible bioturbation, led to the lack of fine laminations in the sediments. This observation is consistent with other studies of Illinois River backwater lake cores such as Cahill and Steele (1986) and Cahill et al. (2008). Conspicuous beds of coarser material, such as sand lenses, were also absent in the cores, as were large concentrations of shells, peat, muck, or woody debris. The lack of large and obvious concentrations of organic matter likely indicate that long-term still-stands of stable wetland conditions did not occur. There was an association worth noting however. In the lake cores 151 and 153, shallower sediments tended to have a uniform low-chroma matrix with no mottles, showed visible undigested plant debris, and had positive reactions to a-a' dipyridyl indicating reduced iron and anaerobic conditions. This unit was 60 cm deep in core 151 and 30 cm deep in core 153. These conditions are characteristic of constantly saturated lacustrine or wetland deposits. Below this unit, slowing of the rate of vibracoring progress during core collection generally corresponded to horizons in the core that were, upon later examination, found to be denser and to have a much lower moisture content than the sediments above. These denser units also showed mottling of soil colors, which is more typical of the oxidizing conditions of a past soil surface than the more typical backwater sediments higher up in the column.

The progression from the lakebed to the sediments at depth did not show a steady progression with depth of density, moisture content, or organic carbon, although moisture content generally decreased with depth.

As expected, low unit density corresponded with high water content, especially in the materials next to the water/lakebed sediment interface. Increases in water content at depth, for example at 45-55 cm in Crane Lake core 153, corresponded to a drop in unit density, perhaps due to a slightly more clayey zone holding water. Perturbations in organic carbon content (such as in core 150) likely represented variable length periods of stable vegetation growth and biomass deposition. Below the depth of 60-70 cm in core 150, organic carbon steadily dropped. This likely corresponds to the soil-like profile in core 151 where organic material would have oxidized.

What seems apparent from the grain size analysis coupled with the radiometric dates is a change in depositional regime between the very late 1800s and the early 1900s, with the earlier period characterized by coarser sediment (more silt and less clay). This change likely represents the change from an open-to-the-river condition to a leveed one, as the levee is documented to have been completed in about 1918. On the 1904 Woerman map, the site was un-leveed and more or less directly connected to the river. Historical records place the organization of a drainage district and leveeing off of the site in 1915-1918. Further, after the site was leveed and row-crop agriculture exposed site materials annually to soil erosion, finer clayey materials would enter the lake regularly. Furthermore, if the lead concentrations from the ICP-MS analyses are applied to the ^{137}Cs dates from the same intervals in the Big Lake core 150, a pattern that makes sense with the known history of automotive lead in the environment lends further credence to extending the rate of ~0.61 cm/yr back to at least approximately 1914 (Figure 40). This grouping of the sediment profiles on either side of a known historical event (levee construction in about 1915-18) lends credence to the age profile of the sediments as determined by the radiometric dating method employed. Assigning dates based on the ^{137}Cs rate prior to 1914 becomes increasingly problematic and would require a secondary dating method such as a palynological study.

The morphological examination of one of the deep Big Lake cores (151) also supports this change in depositional regime. The last interval exhibiting consistent low-chroma lake sediments with undigested plant matter present is at a depth range of 50-60 cm (^{137}Cs date of ~1914). At the next depth interval, 60-70 cm, (^{137}Cs date of ~1897), the sediments were markedly different, with mottling more typical of an exposed and aerobic soil profile. This change would be consistent with levee construction and disconnection of the lake from the river. Prior to the levees, the lake would likely drain down and dry down in the summer and fall of most years, allowing the bed to be exposed, organic matter to be consumed, mottles to form, and consolidation and compaction to occur.

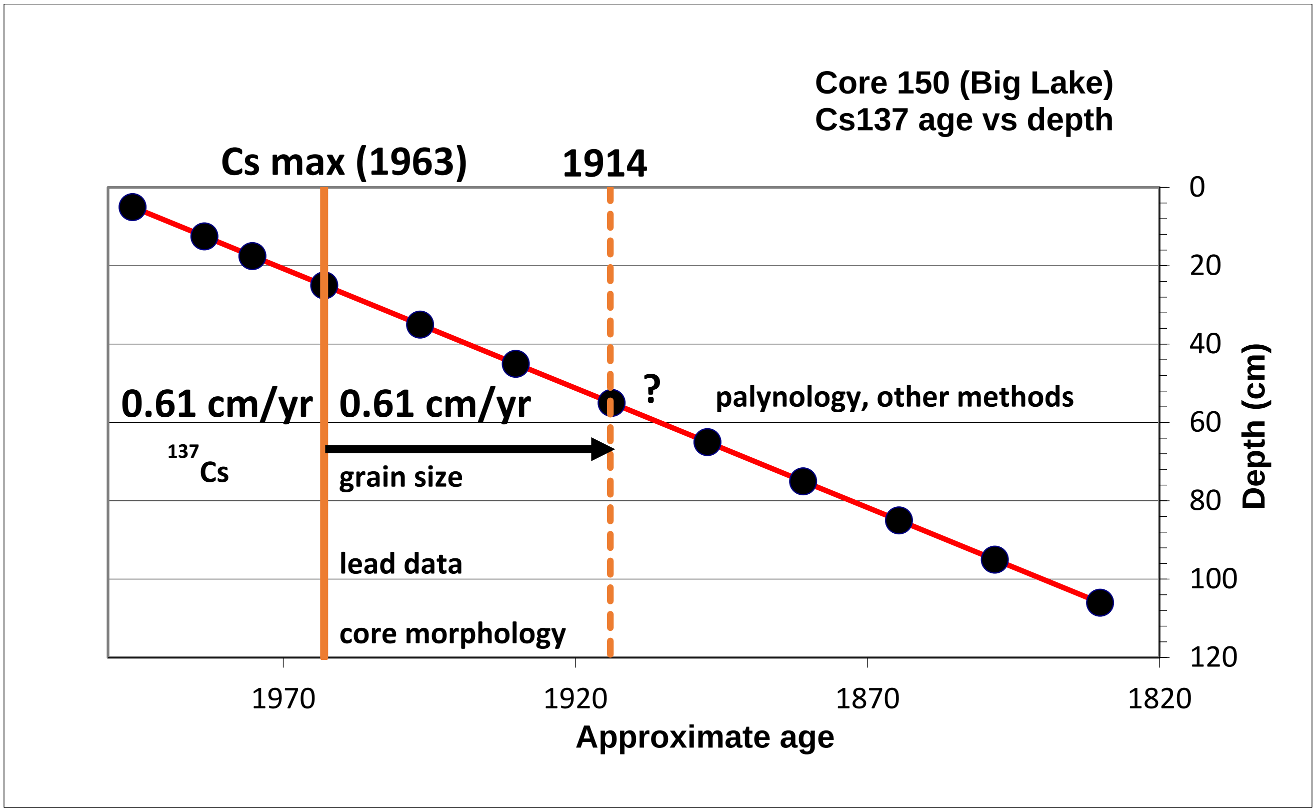


Figure 40: Grain size / lead / core data suggests that ^{137}Cs rates may be valid back to ~1914.

Recent Site-Wide Sedimentation Rates

Considerable difficulty with on-site flooding prevented installation of the sediment stake network for direct sediment depth measurement until 2011. Fortunately, an average site-wide sediment deposition rate of 0.54 cm/yr was measured using nine concreted benchmarks emplaced by ISGS in 2002 and relocated by magnetometer in 2009. The benchmarks were flush with the ground and generally not in locations routinely disturbed by wave action or farming equipment. The sediment also had time to settle and consolidate, and the readings were taken with the site in a dried-down condition.

Readings from the 14 concreted sediment stakes emplaced in 2011 were taken in 2013, 2015 and 2017. These readings were cumulative and in general, the mean depth of sediment increased on-site with each measurement, from 2.35 cm in 2013, to 2.84 cm in 2015, and to 3.53 cm in 2017. When taken over the whole period from 2011 to 2017, the mean site-wide sedimentation rate was 0.61 cm/yr. The fact that this 2011-17 rate is similar to the ^{137}Cs rate is likely coincidental. Firstly, the radiometric dating rates are in the lake itself, not site-wide, and represent at least 40 years (since the 1963 ^{137}Cs activity peak) of deposition, re-mobilization and consolidation at depth. The 2002 to 2009 and 2011-2017 rates were on dry-land areas and excluded the lake and were not subject to compaction at depth.

With the average network-wide sediment depth of 2.35 cm, a rough calculation can be made for the volume of sediment deposited on site. This depth of sediment site-wide translates to 130 ac/ft of sediment, or 209,733 cubic yards, enough to fill 64 Olympic pools or 17,000 standard dump trucks. While it is notable that a significant mean sediment depth of 2.35 cm was recorded on-site in the first site-wide reading of the pegs, sedimentation was primarily due to one long-duration flood event. In the lower elevations, below the terrace, the duration of this flood exceeded 2.5 months and in the higher-elevation areas of the site, the flood persisted for over a month. Measurable sediment was encountered at all stakes. Although more sediment definitely entered the site in subsequent floods, significant re-working and re-depositing of sediment occurred, generally moving sediments from the lake basin outward to higher elevation and more peripheral areas of the site.

After the 2013 read of the sediment stakes, the lower lake basin flooded several times during that period up to the most recent read in 2017. What is notable on the 2015 and 2017 isopach maps is that the stakes where sediment was removed or reduced from the 2013 depths are primarily in the lake basin, which floods regularly. These removals and corresponding increases in sediment depths in the more peripheral areas of the site (north and west portions) indicate that wave action and re-suspension of sediments are pushing sediments north and west to more sheltered areas and higher ground, respectively. Also, these peripheral areas are less prone to long duration inundation and wave action, hence have more quiescent conditions for settling of sediment. These areas also have more well-established plant communities that aid in the anchoring and trapping of sediment.

Floodplain Sediment Storage and Implications for the Lifespan of Big Lake

Backwater wetlands have a significant role in removing sediment from the main stems of rivers, thus limiting channel sedimentation and improving the riverine habitat for aquatic species. Often this sediment trapping role can be at the expense of the health of backwater lakes, wetlands and the diversity of fauna and vegetation therein. For backwater lakes to persist as fish-rearing habitat and waterfowl rest and feeding areas, significant depth and water clarity is required, which is in conflict with repeated influxes and re-working of sediment.

Three sedimentation rates were determined during this study. The first determined by the radiometric dating (~0.61 cm/yr from ~1914-2004). The second rate, directly determined by measuring the sediment depths over concrete benchmarks (0.54 cm/yr from 2002 to 2009). The third, also directly read via on-site stakes (~0.61 cm/yr from 2011 to 2017). If the ^{137}Cs rate from 1963 to 2004 and the direct benchmark and stake measured rates from 2002 to 2017 are applied site-wide, the deposition totals come to a total depth of sediment on site of 35 cm (13.8 in) or 1,932 acre/ft (3,116,959 cubic yards / 953 Olympic pools / 259,746 dump trucks) since 1963.

Using the 0.61 cm/yr rate combined with the Big Lake basin survey volume of 534 acre/ft, the lake filling rate is calculated at 3.92 acre/ft per year. This rate would give the lake a lifespan going forward of about 136 years. As the lake had a similar extent and a similar 2-4 ft (0.6-1.2 m) depth on 1904 mapping of the site, it is likely not a question of simple progressive filling. More likely, the wave-action and re-mobilization of sediments from the lake basin to the more peripheral areas of the site is the probable mechanism by which Big Lake has and will perpetuate itself.

Conclusions

Restoring floodplains and backwater lakes along large rivers by removing levees requires understanding of the tradeoffs between heavy sediment loads along the main stem of the river versus the negative effects of sediment deposition on backwater lakes and wetlands. Analysis of lake sediment cores showed materials consisted of very poorly consolidated silts and clays with no apparent shells, sand lenses, or any distinct laminations. The lack of fine layering in mixed silt and clay sediments such as these is common in shallow backwater lakes subject to occasional disturbance by wave action. Large concentrations of peaty or woody debris were also absent, suggesting no long-standing periods of stable wetland conditions. The average sedimentation rate from about 1914 to 2004 was calculated at roughly 0.61 cm/yr. Direct sedimentation rates were measured at 0.54 cm/yr (2002-2009) and 0.61 cm/yr (2011-2017). When combined with data from a 2006 lakebed survey, these rates would predict infilling of Big Lake completely in about 136 years. However, evidence of re-working of sediments on-site by wave action appears to push sediments away from the lake basin and deposit them in higher elevation and more densely vegetated areas. This wave action results in perpetuating the shallow lake for over a century despite significant inputs of riverine sedimentation.

Recommendations for Further Work

A number of research questions have arisen from this study and may merit further examination.

Can the deposition rates or environmental chronology for the site be pushed further back with any other methods?
Lead-210 (^{210}Pb) dating methods (effective back to 100 years) could also be applied to the spare, untouched cores with appropriate funding to do so. The extra cores could also be sampled for a palynological study to both clarify the existing ^{137}Cs chronology and potentially push the dating of the sediments and deposition rates further back into the 1800s. Information on the environmental and biotic history of the site would also be gleaned.

Is there a correlation between flood duration and sediment deposition rate?
As water levels on the site have been widely and continuously monitored on-site since 2000, an examination of the relationship between sedimentation rates and flood duration would be useful. When the stake network was emplaced in 2011, some stakes were specifically placed at locations with water level dataloggers present in order to facilitate this research.

Are sedimentation rates evolving as the site adjusts to its status as open to the river?
This study is ongoing as the stake network is still in place and will be read at least every two years until ISGS involvement ends at the site. A round of sediment measurements was scheduled for fall 2019, and sediment depths were anticipated to be significant due to a record duration flood on the site in spring 2019.

Are there better methods to measure long-term sedimentation rates?
Other methods of sediment accumulation measurement may be tried alongside the stakes to see if they are more appropriate. These may include artificial horizons such as white feldspar clay or plastic grids, which will not act as a focus for turbulence as the stakes may do during periods of wave activity.

How does the soil profile chemistry from this study compare to other cores taken from lakes in the Illinois River basin? Are lakes that have been continuously open to the river more impacted by heavy metals and other contaminants than this site?
As noted previously, the sediment chemistry data collected for the lake cores have only been minimally utilized in this study. The Big Lake and Crane Lake chemistry data has not been compared to other Illinois River backwater lakes, such as those cored and described in in Cahill and Steele (1986) and Cahill et al. (2008). More detailed examination of these data is planned to compare the deposition rates and concentrations of environmental contaminants from the "isolated" Big Lake core samples to cores from permanently "connected" backwater lakes and other main stem Illinois River sediments.

Are any environmentally regulated constituents present in the soil cores that are above regulatory limits or above levels that have negative implications on biota?
The transport of anthropogenic contaminants from up-basin areas such as the Des Plaines River or Calumet area has been a considerable area of study over the past few decades. However, sediment quality data from lakes in the La Grange reach of the Illinois River are rare, as ISGS/ISWS scientists have only cored two lakes in this pool. Both lakes have a full-time river connection. The opportunity to examine these cores for environmental studies also exists for ISGS, USGS, Illinois Natural History Survey (INHS), or any UIUC (or external) scientists for whatever purpose they choose.

What is the effect of repeated deposition of sediment at the site on floristic quality and vegetation diversity? Do re-mobilized sediments in the lake (turbidity) negatively affect the development of submerged aquatic vegetation?

It may be useful to collaborate with INHS botanists who have been monitoring the vegetation dynamics at the site since at least 2000. It may be interesting to see what effects previously characterized individual sedimentation events had on the wetland vegetation assemblage on site. A research path to pursue might be to determine if a flood that deposits 2.5 cm of sediment site-wide, for example, results in a reduction of the floristic diversity and a reset to invasive or more early-successional species. Anecdotal on-site observations suggest this is so.

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Appendix A: Additional Data

Table A1: Grain size analysis results for cores 150 and 151 from the ISWS lab.

Big Lake 150 — % Finer

													core nose
	depth range (cm)	0-10	10-15	15-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-112
	midpoint (cm)	5	12.5	17.5	25	35	45	55	65	75	85	95	106
	Sample	150-1	150-2	150-3	150-4	150-5	150-6	150-7	150-8	150-9	150-10	150-11	150-12 (B)
Grain Size (mm)	0.0620	99.3	99.9	99.7	100.0	100.0	100.0	100.0	99.1	98.1	98.8	99.5	99.4
	0.0310	97.7	97.7	99.0	98.0	99.9	100.0	100.0	99.1	90.6	89.1	91.6	92.2
	0.0156	86.5	87.7	90.6	88.0	92.7	94.9	93.8	65.5	68.4	63.5	70.2	70.3
	0.0078	72.5	72.6	76.7	75.0	80.1	79.0	76.6	55.5	51.7	44.0	52.3	53.0
	0.0039	59.7	60.3	64.9	64.0	66.6	64.9	60.9	43.5	40.5	34.2	43.0	42.7
	0.0020	51.1	51.3	57.0	55.0	57.2	54.1	52.9	38.3	36.4	30.5	37.2	37.5
Cs-peak age		1996	1984	1975	1963	1947	1930	1914	1897	1881	1865	1848	1830
Cs-onset age		1997	1985	1978	1967	1952	1937	1922	1907	1893	1878	1863	1847

Big Lake 151 — % Finer

													core nose
	depth range (cm)	0-5	5-10	10-15	15-20	20-30	30-40	40-50	50-60	60-70	70-80	80-97	97-110
	midpoint (cm)	2.5	7.5	12.5	17.5	25	35	45	55	65	75	88.5	103.5
	sample	151-1	151-2	151-3	151-4	151-5	151-6	151-7	151-8	151-9	151-10	151-11	151-12 (B)
Grain Size (mm)	0.0620	100.0	100.0	100.0	98.1	100.0	100.0	100.0	99.5	100.0	99.8	99.9	99.3
	0.0310	99.1	99.0	98.8	97.2	100.0	99.8	99.4	98.9	99.4	96.2	98.5	96.9
	0.0156	92.0	90.9	92.5	91.2	94.1	92.7	90.9	91.4	88.7	76.2	80.6	86.8
	0.0078	75.1	74.1	77.8	80.0	82.6	79.3	76.1	75.3	74.1	53.0	60.4	64.9
	0.0039	59.8	62.2	63.4	67.3	69.9	65.2	63.7	71.3	60.8	41.6	47.0	52.8
	0.0020	51.5	52.9	53.2	57.5	60.6	56.8	53.5	54.3	49.8	36.1	40.1	45.0
Cs-peak age		2000	1992	1984	1975	1963	1947	1930	1914	1897	1881	1859	1834
Cs-onset age		2000	1993	1985	1978	1967	1952	1937	1922	1907	1893	1873	1850

Table A2: ICP-MS results for core 150 for selected environmental metals and total, inorganic and organic carbon.

Lab sample #	Core/ sample #	Depth range (cm)	Mid-point (cm)	Tot. C (%)	Inc. C (%)	Org. C (%)	**Cr** (mg/kg)	**Fe** (%)	**Ni** (mg/kg)	**Cu** (mg/kg)	**Zn** (mg/kg)	**As** (mg/kg)	**Cd** (mg/kg)	**Hg** (ug/kg)	**Pb** (mg/kg)
R23808	150-B	100-112	106.0	0.85	0.17	0.68	24.12	4.03	22.20	18.02	136.47	4.78	1.34	63.00	19.71
R23809	150-11	90-100	95.0	0.66	0.25	0.41	25.05	2.76	17.37	15.81	80.38	1.57	0.45	40.00	15.51
R23810	150-10	80-90	85.0	0.95	0.14	0.81	25.86	1.50	15.20	16.64	70.01	0.49	0.32	35.00	13.72
R23811	150-9	70-80	75.0	1.57	0.12	1.45	28.05	1.68	19.11	18.95	80.13	1.39	0.42	47.00	14.43
R23812	150-8	60-70	65.0	1.95	0.17	1.78	31.73	2.09	22.94	19.97	88.99	1.53	0.44	53.00	15.09
R23813	150-7	50-60	55.0	1.90	0.27	1.63	35.89	2.71	27.11	21.39	96.70	2.87	0.41	51.00	17.35
R23814	150-6	40-50	45.0	1.95	0.31	1.64	38.85	3.06	30.11	24.64	104.12	2.90	0.41	65.00	46.73
R23815	150-5	30-40	35.0	2.23	0.13	2.10	38.94	2.96	29.20	24.28	118.79	4.06	0.50	66.00	60.24
R23816	150-4	20-30	25.0	2.01	0.14	1.87	38.78	3.27	31.66	24.55	114.62	6.31	0.52	66.00	26.35
R23817	150-3	15-20	17.5	2.12	0.15	1.97	35.51	3.23	30.74	24.65	137.28	5.26	0.45	75.00	24.42
R23818	150-2	10-15	12.5	1.91	0.18	1.73	28.63	2.94	27.74	23.46	103.99	5.31	0.50	68.00	20.65
R23819	150-1	0-10	5.0	1.96	0.23	1.73	24.08	2.64	25.03	21.37	98.59	4.59	0.36	60.00	18.71
			mean	1.67	0.19	1.48	31.29	2.74	24.87	21.14	102.50	3.42	0.51	57.42	24.41
			min	0.66	0.12	0.41	24.08	1.50	15.20	15.81	70.01	0.49	0.32	35.00	13.72
			max	2.23	0.31	2.10	38.94	4.03	31.66	24.65	137.28	6.31	1.34	75.00	60.24
			n	12	12	12	12	12	12	12	12	12	12	12	12

Table A3: All raw ICP-MS results for cores 150, 153, and 155 (inorganic elements) including replicates and lab standard results.

Sample Number	Depth range (cm)	Location	Tot. C (%) (%)	Inc. C (%) (%)	Org. C (%) (%)	Li (mg/kg)	Be (mg/kg)	B (mg/kg)	Na (mg/kg)	Mg (%)	Al (%)	K (%)	Ca (%)	Sc (mg/kg)	V (mg/kg)	Cr (mg/kg)	Mn (mg/kg)	Fe (%)	Co (mg/kg)	Ni (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Ga (mg/kg)
R23808	100-112	Big Lake 150	0.85	0.17	0.68	13.1	0.8	<1	0.010	0.30	1.67	0.11	0.35	4.4	34	24.1	317	4.03	10.3	22.2	18.0	136	4.91
R23809	90-100		0.66	0.25	0.41	13.6	0.9	<1	0.009	0.31	1.68	0.12	0.32	4.5	33	25.0	217	2.76	6.9	17.4	15.8	80.4	4.78
R23810	80-90		0.95	0.14	0.81	13.0	1.0	<1	0.009	0.26	1.66	0.14	0.29	4.4	35	25.9	209	1.50	5.5	15.2	16.6	70.0	4.69
R23811	70-80		1.57	0.12	1.45	15.9	0.9	<1	0.012	0.30	2.03	0.19	0.31	5.1	38	28.1	230	1.68	6.1	19.1	18.9	80.1	5.56
R23811 Replicate						16.5	1.0	<1	0.012	0.32	2.05	0.20	0.33	5.0	39	28.7	223	1.68	6.1	19.5	18.8	78.8	5.75
R23812	60-70		1.95	0.17	1.78	18.8	1.1	<1	0.014	0.38	2.31	0.23	0.39	5.5	42	31.7	275	2.09	7.2	22.9	20.0	89.0	6.52
R23813	50-60		1.90	0.27	1.63	21.9	1.2	<1	0.014	0.46	2.86	0.28	0.45	6.3	51	35.9	357	2.71	9.4	27.1	21.4	96.7	7.44
R23814	40-50		1.95	0.31	1.64	23.8	1.2	<1	0.013	0.53	3.06	0.30	0.50	6.8	58	38.8	428	3.06	10.4	30.1	24.6	104	8.26
R23815	30-40		2.23	0.13	2.10	22.8	1.3	<1	0.013	0.47	3.05	0.29	0.45	6.5	58	38.9	383	2.96	9.7	29.2	24.3	119	7.99
R23816	20-30		2.01	0.14	1.87	22.5	1.2	<1	0.013	0.50	2.94	0.28	0.48	6.5	58	38.8	453	3.27	10.8	31.7	24.6	115	7.85
R23817	15-20		2.12	0.15	1.97	21.4	1.3	<1	0.011	0.50	2.72	0.26	0.50	6.0	53	35.5	475	3.23	11.1	30.7	24.6	137	7.57
R23818	10-15		1.91	0.18	1.73	16.5	1.0	<1	0.010	0.46	2.03	0.20	0.59	4.9	41	28.6	477	2.94	11.0	27.7	23.5	104	5.88
R23819	0-10		1.96	0.23	1.73	13.6	1.0	<1	0.008	0.42	1.63	0.16	0.65	4.1	35	24.1	531	2.64	9.9	25.0	21.4	98.6	4.96
R23835	surface	Big Lake 149	2.03	0.18	1.85	21.2	1.2	<1	0.014	0.53	2.65	0.29	0.72	5.7	50	34.6	569	2.89	10.6	28.8	21.6	98.3	7.45
R23836	surface	Big Lake 150	2.29	0.24	2.05	20.9	1.1	<1	0.014	0.57	2.51	0.29	0.69	5.7	51	34.8	631	3.02	11.0	29.9	24.0	108	7.75
R23820	72-82	Crane Lake 153	0.86	0.10	0.76	16.2	1.3	<1	0.008	0.43	2.14	0.14	0.46	5.7	43	30.6	447	4.74	14.3	31.9	22.8	105	6.71
R23821	60-72		1.31	0.12	1.19	17.2	1.2	<1	0.009	0.35	2.20	0.16	0.37	5.8	44	31.5	246	2.49	8.9	24.9	23.3	89.7	6.64
R23822	50-60		1.93	0.15	1.78	21.6	1.4	<1	0.011	0.40	2.83	0.24	0.43	6.7	54	38.9	317	2.58	9.6	29.6	26.3	106	7.93
R23823	40-50		1.95	0.25	1.70	22.7	1.3	<1	0.011	0.48	3.01	0.27	0.40	6.9	57	38.3	376	2.85	9.9	29.0	25.3	99.4	9.02
R23824	30-40		2.13	0.24	1.89	24.8	1.5	<1	0.012	0.54	3.26	0.30	0.50	7.3	64	42.3	455	3.44	11.0	32.3	27.2	114	9.47
R23825	20-30		2.07	0.18	1.89	24.8	1.4	<1	0.012	0.53	3.28	0.32	0.52	7.3	65	43.0	476	3.46	11.4	33.1	27.3	123	9.32
R23825 Replicate						25.5	1.3	<1	0.013	0.56	3.40	0.33	0.56	7.4	63	42.6	510	3.56	12.0	33.4	28.1	123	9.58
R23826	10-20		2.16	0.17	1.99	25.7	1.3	<1	0.012	0.59	3.24	0.35	0.56	7.0	61	41.9	568	3.65	12.3	34.0	27.9	119	9.28
R23827	0-10		2.04	0.15	1.89	22.3	1.2	<1	0.011	0.53	2.70	0.30	0.53	6.2	56	36.9	533	3.17	11.5	30.6	25.2	108	8.48
R23837	surface	Crane Lake 153	2.32	0.20	2.12	20.8	1.1	<1	0.013	0.56	2.69	0.29	0.72	5.7	51	34.7	583	3.16	10.8	29.9	24.9	106	7.81
R23828	33-42	Off Lake 155	1.39	0.15	1.24	19.1	1.2	<1	0.010	0.41	2.31	0.16	0.48	5.6	47	32.8	424	3.30	11.3	27.9	22.0	90.3	7.14
R23829	25-33		1.88	0.26	1.62	14.2	1.2	<1	0.008	0.37	1.88	0.13	0.48	4.7	40	26.8	408	2.56	9.2	28.3	24.8	106	5.72
R23830	20-25		2.03	0.20	1.83	14.8	1.2	<1	0.008	0.41	2.07	0.15	0.47	5.0	43	29.1	434	3.09	10.3	27.3	23.3	97.3	5.90
R23831	15-20		2.05	0.26	1.79	18.8	1.2	<1	0.009	0.46	2.60	0.22	0.51	5.8	50	35.0	296	2.88	9.2	29.9	26.1	109	7.50
R23832	10-15		1.86	0.24	1.62	22.2	1.3	<1	0.011	0.51	3.00	0.26	0.55	6.3	59	39.0	397	3.51	10.8	32.0	25.6	114	8.71
R23833	5-10		1.84	0.12	1.72	22.5	1.3	<1	0.012	0.55	3.14	0.29	0.54	6.6	61	39.9	475	3.33	10.6	31.3	25.5	112	9.00
R23834	0-5		1.84	0.14	1.70	23.0	1.3	<1	0.012	0.53	2.92	0.30	0.52	6.2	57	39.0	506	3.39	11.5	31.5	23.2	121	8.79
R23838	surface	Off Lake 155	2.25	0.21	2.04	20.4	1.0	<1	0.012	0.49	2.47	0.25	0.47	5.2	45	31.8	434	2.92	10.4	28.0	23.1	104	7.26
R23838 Replicate						16.4	1.0	<1	0.010	0.44	2.14	0.21	0.46	4.7	41	29.0	446	2.95	10.4	27.0	22.5	130	6.44
R23839		NIST 1944	5.14	0.30	4.84	18.7	0.6	<1	0.383	0.68	0.92	0.21	0.63	2.7	38	200	287	2.53	9.7	69.0	349	582	3.44
	Certified Total Concentrations 1944				(4,4)		(1.6)		(1.9)		5.33	(1.6)	(1.0)	(10.2)	(100)		505	3.53	(14)	76.1	(380)	656	
R23840		NIST 2711	1.93	0.53	1.40	10.8	0.9	<1	0.012	0.61	1.16	0.30	1.99	2.0	38	16.6	447	1.93	7.6	15.7	103	302	4.42
	Certified Total Concentrations 2711		(2)						1.14	1.05	6.53	2.45	2.88	(9)	81.6	(47)	638	2.89	(10)	20.6	114	350	(15)
	Noncertified Leachable Concentrations 2711								0.026	0.81	1.8	0.38	2.10		42	20	490	2.2	8.2	16.0	100	310	
R23841		NIST2709	1.29	0.42	0.87	30.9	0.7	<1	0.032	1.19	1.98	0.32	1.37	6.2	63	65.4	453	2.90	11.9	75.9	30.5	91.0	6.48
	Certified Total Concentrations 2709		(1.2)						1.160	1.51	7.50	2.03	1.89	(12)	112	130	538	3.50	13.4	88	34.6	88	34.6
	Noncertified Leachable Concentrations 2709								0.068	1.4	2.6	0.32	1.5		62	79	470	3.0	12	78	32	78	32
R23842		NIST 8704	3.59	1.03	2.56	25.8	0.7	<1	0.010	0.86	1.12	0.12	2.27	2.6	23	71.7	465	3.31	12.0	39.0	87.6	381	3.90
	Certified Total Concentrations 8704		3.35						0.553	1.20	6.10	2.00	2.64	11.26	94.6	121.9	544	3.97	13.57	42.9		408	
	USGS GXR-6 Soil (B zone): NC					26.4	0.9	<1	0.039	0.40	6.99	1.07	0.16	21.1	158	74.9	1000	5.50	12.8	22.8	64.2	114	17.0
						32.0	**1.4**	**10**	**0.104**	**0.609**	**17.7**	**1.87**	**0.18**		**186**	**96**	**1,007**	**5.58**	**13.8**	**27**	**66**	**118**	**35**
	USGS GXR-2 Soil (B zone) : UT					43.0	0.9	<1	0.071	0.46	3.07	0.57	0.65	3.7	39	21.6	947	1.75	8.0	15.9	73.8	506	9.65
						54.0	**1.7**	**42**	**0.556**	**0.850**	**16.5**	**1.37**	**0.93**		**52**	**36**	**1,007**	**1.86**	**8.6**	**21**	**76**	**530**	**37**
	USGS GXR-1 Jasperoid :UT					4.5	0.8	<1	0.023	0.14	0.30	0.03	0.81	1.0	76	7.8	864	25.0	7.9	40.1	1220	779	4.60
						8.2	**1.22**	**15**	**0.052**	**0.217**	**3.15**	**0.05**	**0.96**		**80**	**12**	**852**	**23.6**	**8.2**	**41**	**1,110**	**760**	**13.8**
	USGS GXR-4 -Porphyry Copper Mill					8.9	1.3	0	0.058	1.39	2.33	1.52	0.74	5.5	70	47.8	147	2.78	12.4	34.1	5440	61.0	9.61
	Heads : Utah					**11.1**	**1.9**	**4.5**	**0.564**	**1.658**	**7.20**	**4.01**	**1.01**		**87**	**64**	**155**	**3.09**	**14.6**	**42**	**6,520**	**73**	**20**
	SO-2 Canadian Soil																						
	(Mercury Only)																						

Table A3 (cont'd): All raw ICP-MS results for cores 150, 153, and 155 (inorganic elements) including replicates and lab standard results.

Sample Number	Depth range	Location	Ge	As	Se	Rb	Sr	Y	Zr	Nb	Mo	Ag	Cd	In	Sn	Sb	Te	Cs	Ba	La	Ce	Pr
	(cm)		(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
R23808	100-112	Big Lake 150	<0.1	4.8	0.7	12.3	17.7	10.8	6.8	0.2	0.44	<0.002	1.3	0.11	0.14	0.11	0.03	0.7	134	20.8	35.6	5.4
R23809	90-100		<0.1	1.6	1.2	11.6	17.0	11.3	6.6	0.2	0.17	<0.002	0.4	0.04	0.07	0.13	0.05	0.6	122	21.6	37.8	5.7
R23810	80-90		<0.1	0.5	0.3	16.1	20.4	12.8	8.9	0.4	0.25	<0.002	0.3	0.03	0.09	0.19	0.03	0.8	138	26.7	44.6	6.9
R23811	70-80		<0.1	1.4	0.2	22.5	25.5	14.0	9.0	0.5	0.47	<0.002	0.4	0.03	0.12	0.19	<0.02	1.1	149	27.2	45.9	7.0
R23811 Replicate			<0.1	1.0	0.7	23.2	26.3	13.7	8.9	0.5	0.45	<0.002	0.4	0.03	0.11	0.18	<0.02	1.0	151	27.4	46.3	7.1
R23812	60-70		<0.1	1.5	0.7	27.0	28.6	14.8	8.8	0.5	0.53	<0.002	0.4	0.03	0.14	0.18	<0.02	1.2	177	28.7	46.2	7.1
R23813	50-60		<0.1	2.9	0.7	32.7	31.6	16.0	9.1	0.5	0.57	<0.002	0.4	0.03	0.20	0.22	<0.02	1.4	226	30.0	47.7	7.5
R23814	40-50		<0.1	2.9	1.0	35.4	32.6	17.2	9.7	0.6	0.71	<0.002	0.4	0.04	0.27	0.24	<0.02	1.5	241	30.7	48.7	7.6
R23815	30-40		<0.1	4.1	1.2	34.7	29.9	16.5	9.5	0.6	0.75	<0.002	0.5	0.04	0.32	0.27	<0.02	1.5	218	30.1	48.5	7.4
R23816	20-30		<0.1	6.3	0.6	35.3	30.2	16.7	9.0	0.7	0.53	<0.002	0.5	0.04	0.32	0.25	<0.02	1.4	217	29.1	45.9	7.2
R23817	15-20		<0.1	5.3	1.2	27.9	27.6	16.0	7.5	0.7	0.54	<0.002	0.5	0.03	0.33	0.24	0.07	1.0	217	28.5	44.9	7.0
R23818	10-15		<0.1	5.3	1.1	19.0	22.1	14.4	5.9	0.6	0.54	<0.002	0.5	0.03	0.25	0.23	0.04	0.6	187	25.2	41.0	6.4
R23819	0-10		<0.1	4.6	0.9	15.9	20.9	13.3	4.5	0.5	0.51	<0.002	0.4	0.03	0.16	0.20	0.06	0.4	175	21.4	35.0	5.5
R23835	surface	Big Lake 149	<0.1	3.4	1.5	30.1	31.5	14.5	6.1	0.5	0.58	<0.002	0.5	0.03	0.25	0.29	<0.02	1.2	204	25.6	41.5	6.6
R23836	surface	Big Lake 150	<0.1	4.5	0.9	30.1	34.2	15.6	5.4	0.6	0.45	<0.002	0.5	0.04	0.27	0.24	0.09	1.2	214	27.1	43.4	6.9
R23820	72-82	Crane Lake 153	<0.1	8.5	0.5	18.1	24.7	16.3	8.9	0.2	0.47	<0.002	0.3	0.03	0.16	0.19	<0.02	0.7	209	25.6	43.2	6.6
R23821	60-72		<0.1	1.5	1.2	20.3	25.5	16.7	9.0	0.3	0.32	<0.002	0.3	0.03	0.15	0.21	<0.02	0.8	225	27.9	46.5	7.2
R23822	50-60		<0.1	3.2	0.6	30.0	32.1	18.5	11.4	0.6	0.67	<0.002	0.4	0.03	0.22	0.23	0.03	1.3	273	31.8	53.2	8.3
R23823	40-50		<0.1	4.0	0.9	33.6	31.7	17.0	11.0	0.7	0.75	<0.002	0.4	0.04	0.26	0.28	<0.02	1.6	274	29.4	48.3	7.6
R23824	30-40		<0.1	4.6	0.8	38.5	34.2	18.2	11.2	0.6	0.78	<0.002	0.5	0.04	0.34	0.28	0.05	1.6	272	30.8	48.4	7.7
R23825	20-30		<0.1	4.8	1.0	38.8	34.7	17.4	9.2	0.6	0.57	<0.002	0.5	0.04	0.37	0.31	0.02	1.7	253	29.3	46.8	7.3
R23825 Replicate			<0.1	4.6	1.1	40.4	35.3	18.0	9.5	0.6	0.60	<0.002	0.5	0.04	0.37	0.31	<0.02	1.6	258	30.8	48.3	7.6
R23826	10-20		<0.1	6.0	1.1	37.2	35.2	17.4	8.5	0.7	0.53	<0.002	0.5	0.04	0.39	0.27	0.05	1.4	254	30.1	47.4	7.5
R23827	0-10		<0.1	5.0	1.0	31.6	31.0	15.3	7.4	0.7	0.54	<0.002	0.5	0.04	0.30	0.25	0.03	1.2	227	27.0	43.5	6.8
R23837	surface	Crane Lake 153	<0.1	3.5	1.2	29.9	32.0	15.5	6.3	0.6	0.47	<0.002	0.5	0.03	0.28	0.26	0.04	1.1	223	26.8	42.6	6.9
R23828	33-42	Off Lake 155	<0.1	4.3	0.7	23.5	26.9	16.1	5.7	0.4	0.41	<0.002	0.3	0.03	0.18	0.21	0.05	1.2	225	27.9	46.9	7.2
R23829	25-33		<0.1	3.6	0.5	17.3	22.8	16.4	3.3	0.4	0.33	<0.002	0.4	0.03	0.13	0.21	<0.02	0.6	204	26.2	42.2	6.8
R23830	20-25		<0.1	6.3	0.8	20.3	23.9	17.0	4.9	0.5	0.61	<0.002	0.4	0.03	0.20	0.22	0.03	0.7	223	28.2	43.7	7.2
R23831	15-20		<0.1	4.7	1.0	27.8	27.9	16.7	6.1	0.8	0.49	<0.002	0.4	0.04	0.30	0.33	0.03	0.9	230	29.0	46.0	7.3
R23832	10-15		<0.1	6.0	0.8	35.5	32.5	17.6	6.6	0.8	0.58	<0.002	0.5	0.04	0.31	0.34	0.03	1.4	241	30.4	47.2	7.6
R23833	5-10		<0.1	5.6	1.2	35.8	32.9	17.4	6.3	0.7	0.65	<0.002	0.4	0.04	0.33	0.39	0.03	1.5	264	30.9	48.7	7.8
R23834	0-5		<0.1	5.7	0.9	34.8	33.3	16.4	6.1	0.6	0.52	<0.002	0.3	0.04	0.30	0.37	<0.02	1.4	218	30.0	48.1	7.6
R23838	surface	Off Lake 155	<0.1	4.7	0.6	26.1	27.8	15.7	3.6	0.7	0.42	<0.002	0.4	0.04	0.25	0.27	<0.02	0.9	201	27.6	44.8	7.0
R23838 Replicate			<0.1	4.7	0.5	21.6	23.7	14.8	3.2	0.7	0.43	<0.002	0.5	0.03	0.21	0.29	0.02	0.7	190	26.3	42.1	6.6
R23839		NIST 1944	<0.1	15.3	1.5	12.8	52.1	10.3	2.3	0.9	3.88	6.27	8.1	0.08	16.3	1.94	0.48	0.7	62.2	12.5	20.7	3.4
	Certified Total Concentrations 1944			18.9	(1.4)	(14)						(6.4)	8.8		(42)	(5)		(3.0)		(39)	(65)	
R23840		NIST 2711	<0.1	94.7	1.5	22.0	42.6	14.9	2.6	1.4	0.93	4.27	37.1	0.89	0.79	7.86	1.62	1.6	177	19.2	30.6	4.7
	Certified Total Concentrations 2711			105	1.52	(110)	245.3	(25)	(230)		(1.6)	4.63	41.70	(1.1)		19.4		(6.1)	726	(40)	(69)	
	Noncertified Leachable Concentrations 2711			90.0			50				<2	4	40			<10			200			
R23841		NIST2709	<0.1	16.2	1.2	27.8	96.2	10.6	2.5	0.4	1.16	0.076	0.3	0.03	0.21	1.15	0.06	1.9	376	15.0	25.6	3.7
	Certified Total Concentrations 2709		106	(14)		17.7	1.57	(96)	231	(18)	(160)		(2)	0.41	0.38			7.9		(5.3)	968	23
	Noncertified Leachable Concentrations 2709		100			<20			101				<2		<1			<10			398	
R23842		NIST 8704	<0.1	15.5	1.2	12.0	35.1	11.1	1.6	0.3	3.23	0.155	2.9	0.07	3.34	1.59	0.14	1.4	88.2	10.2	18.9	3.1
	Certified Total Concentrations 8704												2.94			3.07		5.83	413		66.5	
	USGS GXR-6 Soil (B zone): NC		<0.1	224	0.5	66.0	32.8	6.28	10.3	<0.1	0.47	<0.002	0.1	0.06	0.29	0.36	-0.02	3.3	982	10.9	25.5	2.8
				330	**0.94**	**90**	**35**	**14**	**110**	**7.5**	**2.4**	**1.3**	**1**	**0.26**	**1.7**	**3.6**	**0.018**	**4.2**	**1,300**	**13.9**	**36**	
	USGS GXR-2 Soil (B zone) : UT		<0.1	10.4	0.5	50.0	85.1	9.98	11.4	1.9	0.66	17.4	3.6	0.04	0.28	9.10	0.14	3.6	1180	20.0	33.6	4.6
				25	**0.61**	**78**	**160**	**17**	**269**	**11**	**2.1**	**17**	**4.1**	**0.252**	**1.7**	**49**	**0.69**	**5.2**	**2,240**	**25.6**	**51.4**	
	USGS GXR-1 Jasperoid :UT		1.2	402	13.2	2.1	156	27.0	8.0	<0.1	17.1	33.5	2.5	0.70	9.93	50.0	10.2	2.6	389	4.3	8.23	1.3
				427	**16.6**	**14**	**275**	**32**	**38**	**0.8**	**18**	**31**	**3.3**	**0.77**	**54**	**122**	**13**	**3**	**750**	**7.5**	**17**	
	USGS GXR-4 -Porphyry Copper Mill		0.2	94.9	4.5	86.0	70.7	10.0	8.0	0.1	271	2.94	0.1	0.17	1.98	1.58	0.75	2.3	31.1	42.3	63.5	8.9
	Heads : Utah			**98**	**5.6**	**160**	**221**	**14**	**186**	**10**	**310**	**4**	**0.86**	**0.27**	**5.6**	**4.8**	**0.97**	**2.8**	**1,640**	**64.5**	**102**	
	SO-2 Canadian Soil																					
	(Mercury Only)																					

Table A3 (cont'd): All raw ICP-MS results for cores 150, 153, and 155 (inorganic elements) including replicates and lab standard results.

Sample Number	Depth range (cm)	Location	Nd (mg/kg)	Sm (mg/kg)	Eu (mg/kg)	Gd (mg/kg)	Tb (mg/kg)	Dy (mg/kg)	Ho (mg/kg)	Er (mg/kg)	Tm (mg/kg)	Yb (mg/kg)	Lu (mg/kg)	Hf (mg/kg)	Ta (mg/kg)	W (mg/kg)	Re (mg/kg)	Au (ug/kg)	Hg (ug/kg)	Tl (mg/kg)	Pb (mg/kg)	Bi (mg/kg)	Th (mg/kg)	U (mg/kg)
R23808	100-112	Big Lake 150	21.2	4.3	0.9	3.7	0.5	2.3	0.4	1.1	0.1	0.9	0.1	0.2	<0.05	<0.1	0.004	<0.2	63	0.15	19.7	0.20	5.8	0.8
R23809	90-100		21.5	4.6	0.9	4.2	0.5	2.5	0.5	1.1	0.2	0.9	0.1	0.2	<0.05	<0.1	0.002	<0.2	40	0.17	15.5	0.15	6.2	0.9
R23810	80-90		25.6	5.4	1.0	4.7	0.6	2.8	0.5	1.3	0.2	1.0	0.1	0.2	<0.05	<0.1	<0.001	<0.2	35	0.18	13.7	0.05	6.7	1.1
R23811	70-80		26.5	5.5	1.1	5.0	0.6	3.0	0.6	1.3	0.2	1.1	0.1	0.2	<0.05	<0.1	<0.001	<0.2	47	0.23	14.4	<0.02	6.9	1.0
R23811 Replicate			26.9	5.4	1.1	4.7	0.6	3.0	0.6	1.3	0.2	1.1	0.1	0.2	<0.05	<0.1	0.001	<0.2	48	0.23	14.2	<0.02	6.8	0.9
R23812	60-70		27.6	5.6	1.1	4.9	0.6	3.0	0.6	1.4	0.2	1.2	0.2	0.2	<0.05	<0.1	-0.001	<0.2	53	0.25	15.1	<0.02	6.7	1.1
R23813	50-60		28.3	5.9	1.2	5.0	0.7	3.3	0.6	1.6	0.2	1.2	0.2	0.2	<0.05	<0.1	<0.001	<0.2	51	0.30	17.4	<0.02	7.2	1.3
R23814	40-50		29.1	5.9	1.2	5.4	0.7	3.5	0.6	1.6	0.2	1.3	0.2	0.2	<0.05	<0.1	<0.001	<0.2	65	0.33	46.7	0.08	7.2	1.4
R23815	30-40		29.0	5.8	1.2	5.3	0.6	3.4	0.6	1.6	0.2	1.3	0.2	0.2	<0.05	<0.1	<0.001	<0.2	66	0.36	60.2	0.10	7.3	1.5
R23816	20-30		27.3	5.5	1.2	5.0	0.6	3.2	0.6	1.5	0.2	1.2	0.2	0.2	<0.05	<0.1	<0.001	<0.2	66	0.34	26.4	0.11	7.4	1.2
R23817	15-20		26.6	5.5	1.2	5.1	0.7	3.2	0.6	1.6	0.2	1.3	0.2	0.2	<0.05	<0.1	<0.001	<0.2	75	0.36	24.4	0.13	6.7	1.1
R23818	10-15		24.4	5.1	1.1	4.8	0.6	3.0	0.5	1.4	0.2	1.1	0.2	0.1	<0.05	<0.1	<0.001	<0.2	68	0.27	20.7	0.11	5.8	1.0
R23819	0-10		21.0	4.3	0.9	4.0	0.5	2.8	0.5	1.3	0.2	1.0	0.1	<0.1	<0.05	<0.1	<0.001	<0.2	60	0.22	18.7	0.12	4.9	0.9
R23835	surface	Big Lake 149	24.5	5.1	1.0	4.4	0.6	3.0	0.6	1.3	0.2	1.1	0.2	0.1	<0.05	<0.1	<0.001	<0.2	68	0.30	21.6	<0.02	6.5	1.1
R23836	surface	Big Lake 150	26.4	5.3	1.1	4.8	0.6	3.1	0.6	1.4	0.2	1.2	0.2	<0.1	<0.05	<0.1	<0.001	<0.2	72	0.36	23.0	0.04	6.5	0.9
R23820	72-82	Crane Lake 153	25.8	5.6	1.2	5.2	0.7	3.3	0.6	1.6	0.2	1.3	0.2	0.2	<0.05	<0.1	<0.001	<0.2	34	0.21	17.9	0.16	7.9	1.1
R23821	60-72		28.6	5.7	1.2	5.3	0.7	3.4	0.6	1.5	0.2	1.3	0.2	0.2	<0.05	<0.1	<0.001	<0.2	47	0.23	17.1	0.03	7.5	1.4
R23822	50-60		31.9	6.5	1.3	6.1	0.8	3.8	0.7	1.8	0.2	1.5	0.2	0.3	<0.05	<0.1	<0.001	<0.2	59	0.31	19.2	0.08	8.2	1.5
R23823	40-50		28.5	5.9	1.3	5.5	0.7	3.6	0.7	1.7	0.2	1.4	0.2	0.3	<0.05	<0.1	<0.001	<0.2	51	0.35	19.2	0.13	8.0	1.5
R23824	30-40		29.2	5.8	1.2	5.3	0.7	3.6	0.7	1.6	0.2	1.4	0.2	0.2	<0.05	<0.1	<0.001	<0.2	64	0.40	24.6	0.14	8.2	1.7
R23825	20-30		27.8	5.8	1.2	5.2	0.7	3.5	0.7	1.7	0.2	1.3	0.2	0.2	<0.05	<0.1	<0.001	<0.2	68	0.39	26.9	0.09	7.8	1.4
R23825 Replicate			29.6	6.2	1.3	5.6	0.7	3.5	0.7	1.7	0.2	1.4	0.2	0.2	<0.05	<0.1	<0.001	<0.2	74	0.40	27.5	0.09	8.0	1.5
R23826	10-20		28.2	5.9	1.2	5.1	0.7	3.5	0.7	1.6	0.2	1.3	0.2	0.2	<0.05	<0.1	<0.001	<0.2	71	0.44	24.6	0.14	7.4	1.2
R23827	0-10		26.4	5.5	1.1	4.6	0.6	3.1	0.6	1.5	0.2	1.2	0.2	0.1	<0.05	<0.1	<0.001	<0.2	63	0.36	21.4	0.11	6.7	1.0
R23837	surface	Crane Lake 153	25.9	5.3	1.1	4.6	0.6	3.1	0.6	1.5	0.2	1.2	0.2	0.1	<0.05	<0.1	<0.001	<0.2	70	0.34	21.3	0.10	6.6	1.1
R23828	33-42	Off Lake 155	27.7	5.9	1.2	5.2	0.7	3.4	0.6	1.5	0.2	1.3	0.2	<0.1	<0.05	<0.1	<0.001	<0.2	27	0.27	17.9	0.09	6.6	1.4
R23829	25-33		26.7	5.6	1.2	5.2	0.7	3.3	0.6	1.6	0.2	1.3	0.2	<0.1	<0.05	<0.1	<0.001	<0.2	34	0.21	20.4	0.13	5.3	1.5
R23830	20-25		27.7	5.8	1.2	5.1	0.7	3.4	0.7	1.7	0.2	1.3	0.2	<0.1	<0.05	<0.1	0.001	<0.2	36	0.25	20.0	0.16	6.1	1.5
R23831	15-20		27.3	5.6	1.2	5.2	0.7	3.3	0.6	1.6	0.2	1.3	0.2	0.1	<0.05	<0.1	<0.001	<0.2	43	0.31	25.0	0.12	6.5	1.4
R23832	10-15		28.2	5.8	1.2	5.2	0.7	3.5	0.7	1.7	0.2	1.4	0.2	0.1	<0.05	<0.1	<0.001	<0.2	44	0.35	26.0	0.13	6.7	1.5
R23833	5-10		30.1	6.1	1.2	5.4	0.7	3.7	0.7	1.7	0.2	1.4	0.2	0.1	<0.05	<0.1	<0.001	<0.2	46	0.38	26.7	0.09	7.4	1.5
R23834	0-5		29.0	5.9	1.2	5.2	0.7	3.3	0.6	1.6	0.2	1.3	0.2	<0.1	<0.05	<0.1	<0.001	<0.2	47	0.37	26.7	0.07	7.3	1.1
R23838	surface	Off Lake 155	26.2	5.4	1.1	4.6	0.6	3.1	0.6	1.5	0.2	1.2	0.2	<0.1	<0.05	<0.1	<0.001	<0.2	66	0.30	21.8	0.09	5.3	0.9
R23838 Replicate			25.8	5.2	1.1	4.6	0.6	3.0	0.6	1.4	0.2	1.1	0.2	<0.1	<0.05	<0.1	<0.001	<0.2	69	0.27	21.0	0.11	4.9	0.9
R23839		NIST 1944	13.2	3.1	0.6	3.0	0.4	2.1	0.4	1.0	0.1	0.9	0.1	<0.1	<0.05	0.9	<0.001	65.5	3,346	0.27	298	1.60	2.8	1.5
	Certified Total Concentrations 1944				(1.3)													(100)	3,400	(0.59)	330		(13)	(3.1)
R23840		NIST 2711	17.6	3.6	0.6	3.4	0.5	2.6	0.5	1.4	0.2	1.3	0.2	<0.1	<0.05	0.3	<0.001	35.7	6,083	1.48	1040	2.62	3.2	0.9
	Certified Total Concentrations 2711		(31)	(5.9)	(1.1)							(2.7)		*7.3*		*3*		*30*	6,250	2.47	1,162	(7.3)	(14)	(2.6)
	Noncertified Leachable Concentrations 2711																				1,100			
R23841		NIST2709	13.7	2.9	0.6	2.8	0.4	1.9	0.4	1.0	0.1	0.9	0.1	<0.1	<0.05	<0.1	0.002	103	1,498	0.30	13.5	0.17	6.3	1.5
	Certified Total Concentrations 2709		(42)		(3.8)	(0.9)		(1.6)		3.7		2		300	1400	0.74	18.9	(3.7)	1,400	0.74	18.9		(11)	(3)
	Noncertified Leachable Concentrations 2709																13.0				13.0			
R23842		NIST 8704	13.2	3.4	0.7	3.4	0.5	2.3	0.4	1.0	0.1	0.9	0.1	<0.1	<0.05	0.2	<0.001	<0.2	1,157	0.53	142	0.56	2.1	0.7
	Certified Total Concentrations 8704				1.31									8.4							150.0		9.07	3.09
	USGS GXR-6 Soil (B zone): NC		9.57	2.2	0.5	1.8	0.3	1.4	0.3	0.7	0.1	0.8	<0.1	0.2	<0.05	<0.1	<0.001	39.7		1.70	97.0	<0.02	3.5	0.8
			13	**2.67**	**0.76**	**2.97**	**0.415**	**2.8**			**0.032**	**2.4**	**0.33**	**4.3**	**0.485**	**1.9**		**95**		**2.2**	**101**	**0.29**	**5.3**	**1.54**
	USGS GXR-2 Soil (B zone) : UT		15.3	3.1	0.5	2.6	0.3	1.9	0.4	1.0	0.1	0.8	0.1	0.1	<0.05	<0.1	<0.001	58.5	2,858	0.55	636	0.07	3.3	1.4
			19	**3.5**	**0.81**	**3.3**	**0.48**	**3.3**			**0.3**	**2.04**	**0.27**	**8.3**	**0.9**	**1.9**		**36**	**2,900**	**1.03**	**690**	**0.69**	**8.8**	**2.9**
	USGS GXR-1 Jasperoid :UT		4.31	2.2	0.5	3.4	0.7	4.2	0.9	2.4	0.3	2.2	0.3	0.1	<0.05	132	<0.001	3,090	3,995	0.37	706	1732	1.4	31.8
			18	**2.7**	**0.69**	**4.2**	**0.83**	**4.3**			**0.43**	**1.9**	**0.28**	**0.96**	**0.175**	**164**		**3,300**	**3,900**	**0.39**	**730**	**1,380**	**2.44**	**34.9**
	USGS GXR-4 -Porphyry Copper Mill		29.0	5.0	1.1	3.6	0.4	2.1	0.4	0.9	0.1	0.8	0.1	0.2	-0.08	12.0	0.141	311	104	2.25	41.1	24.4	15.7	4.2
	Heads : Utah		**45**	**6.6**	**1.63**	**5.25**	**0.36**	**2.6**			**0.21**	**1.6**	**0.17**	**6.3**	**0.79**	**30.8**		**470**	**110**	**3.2**	**52**	**19**	**22.5**	**6.2**
	SO-2 Canadian Soil																		76					
	(Mercury Only)																		**72 - 91**					